LBNE Photon Detector System
Performance Studies at TallBo

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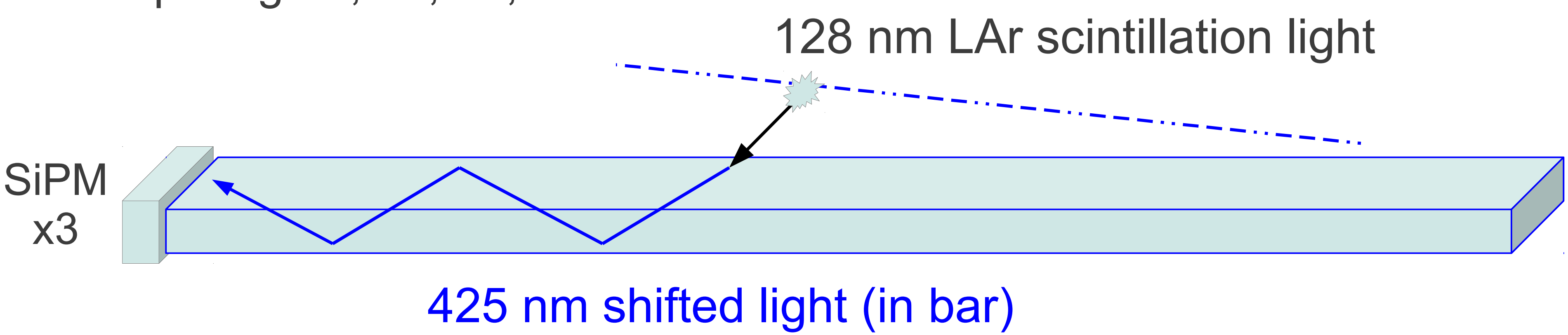
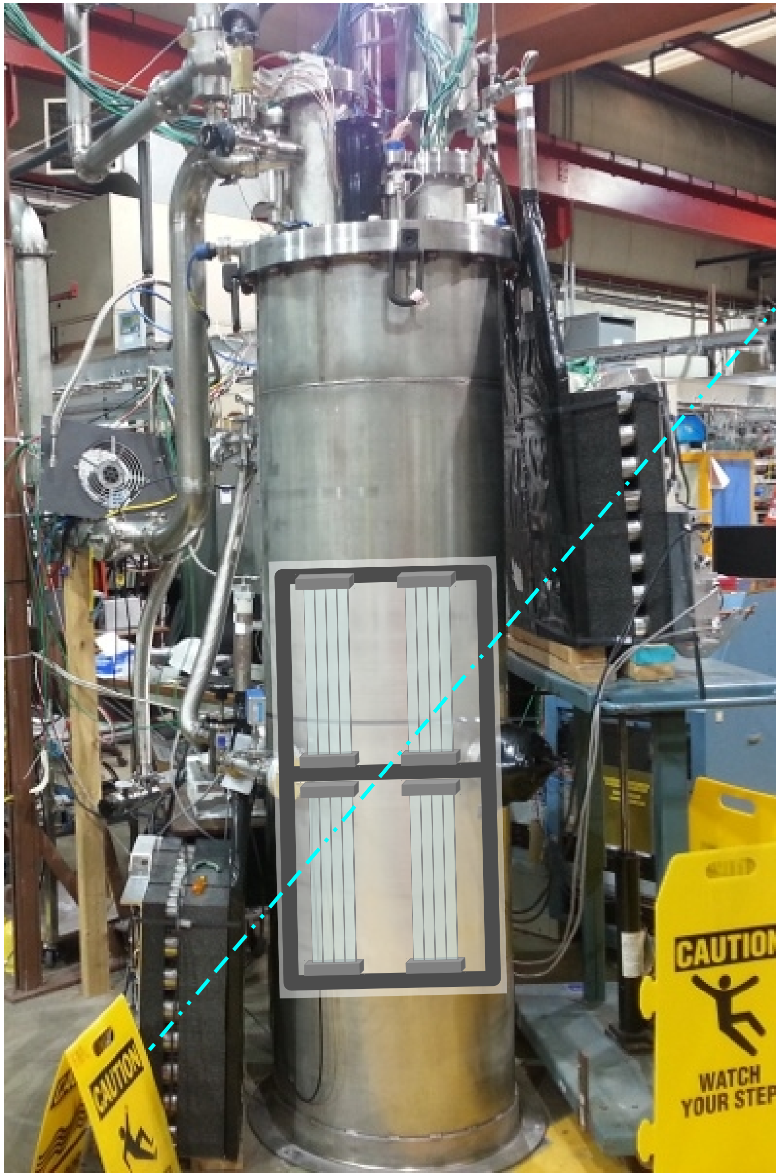
PD Waveguide Design

- Acrylic bar spray-coated with wavelength shifting compound
  - Inspired by design from MIT
  - 6 mm x 1 in x 20 in
    - 1 m long in FD, 4 per paddle
  - Wavelength shifter (WLS) melted into surface
    - Tetraphenyl butadiene (TPB) or
    - 1,4-bis-(o-methyl-styryl)-benzene (bis-MSB)
  - Comparing 10, 20, 35, & 50 coats



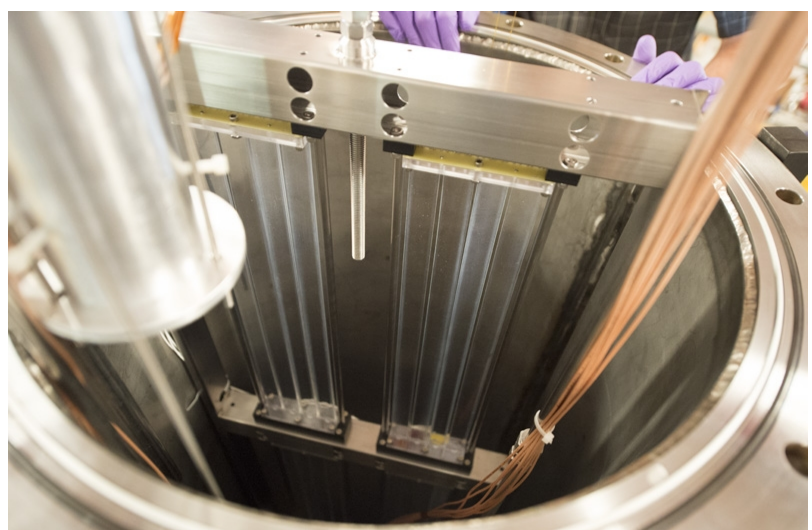
- 3 Silicon Photomultipliers (SiPM) read out end of bar
  - Strongly reverse-biased array of photodiodes
  - SensL MicroFB-60035-SMT
  - 6 mm x 6 mm active area (18960 microcells)
  - 24.5 V bias (gain of a few x10^6)
  - Signal into shaper/amplifier (gain ~200)

- 4 PD paddle prototypes
  - 4 bars per paddle
    - 14 flash-heated (IU)
    - 2 hand-painted (MIT)
- Hodoscope array and scint. paddles
  - 4-fold coincidence for cosmic ray selection and track reconstruction
- Goals
  - Exercise readout of multiple paddles
  - Study relative light yields from various waveshifter/coating combinations
  - Study scintillation detection from cosmics with a large variety of tracks through LAr volume
- Two operating modes
  - Cosmic hodoscope trigger
  - Free run (self-triggered)



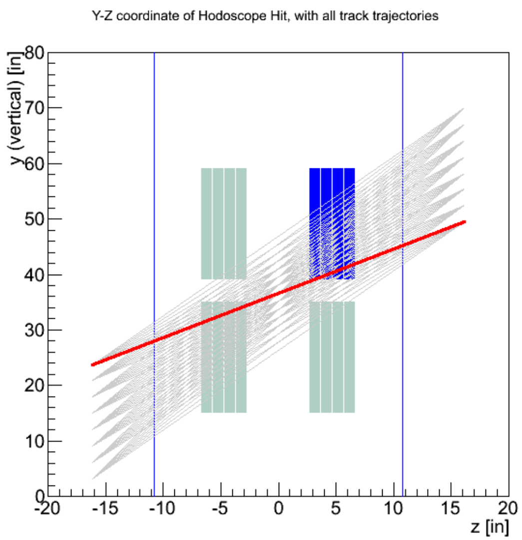
Setup at TallBo

- Installation on October 11, LAr on October 16/17
- Successful operation until October 31

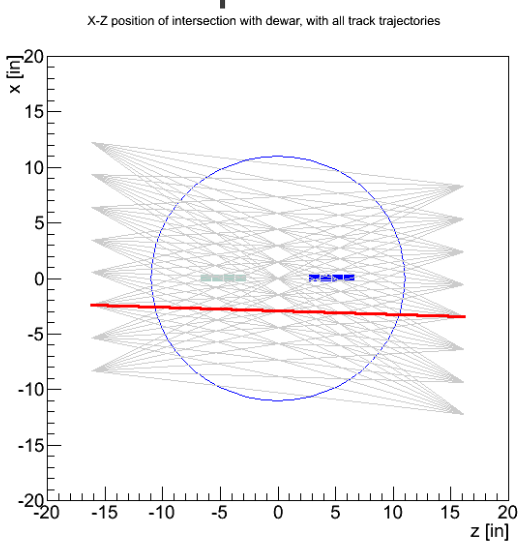


- Variety of track trajectories through hodoscope to study

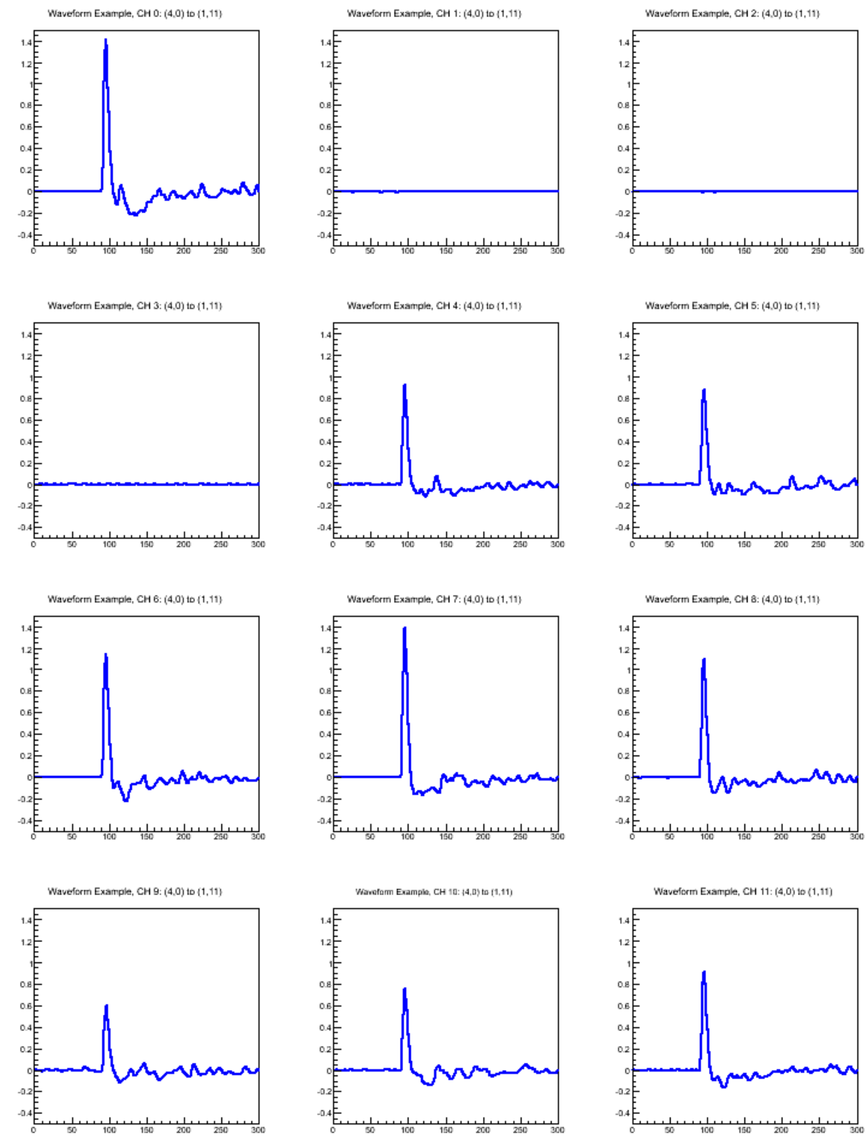
Side View



Top View



Example Track viewed by Paddle B



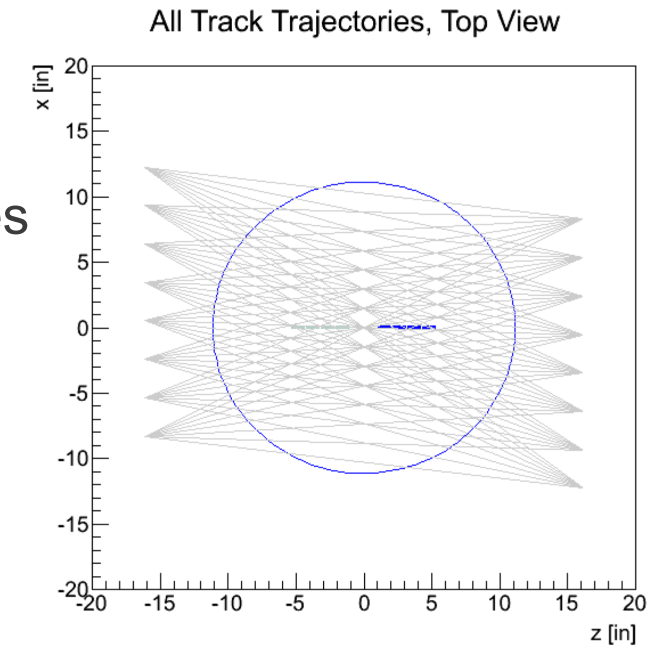
TPB-20

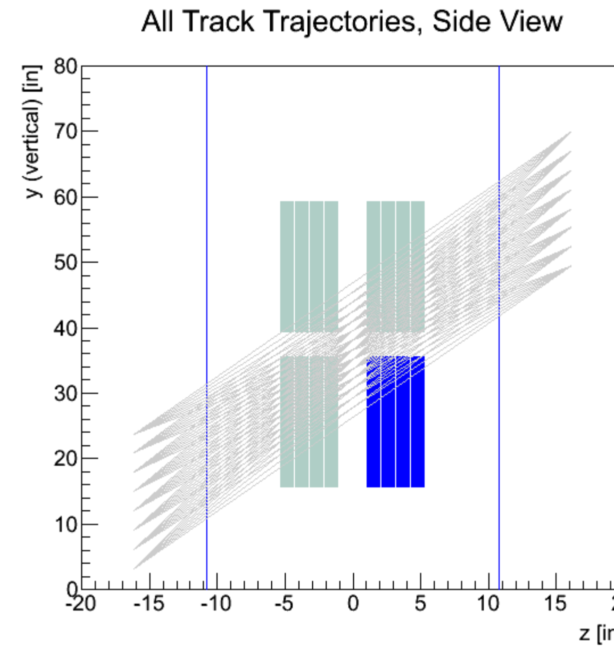
TPB-20

Bis-MSB 35

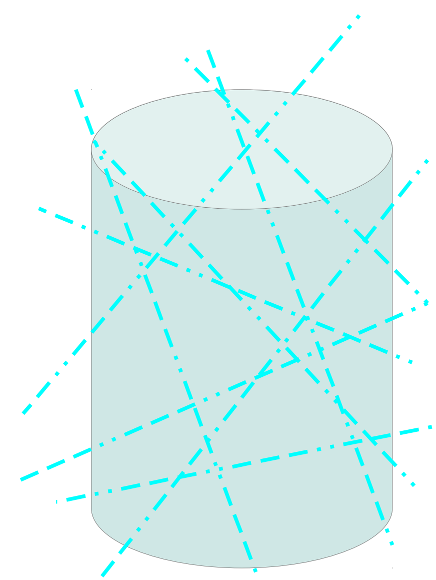
Bis-MSB 35

- Hodoscope track selection great, but makes cross-paddle comparisons difficult
  - Similar coverage within each paddle
    - On-diagonal paddles best exposed
  - Uneven coverage of different paddles





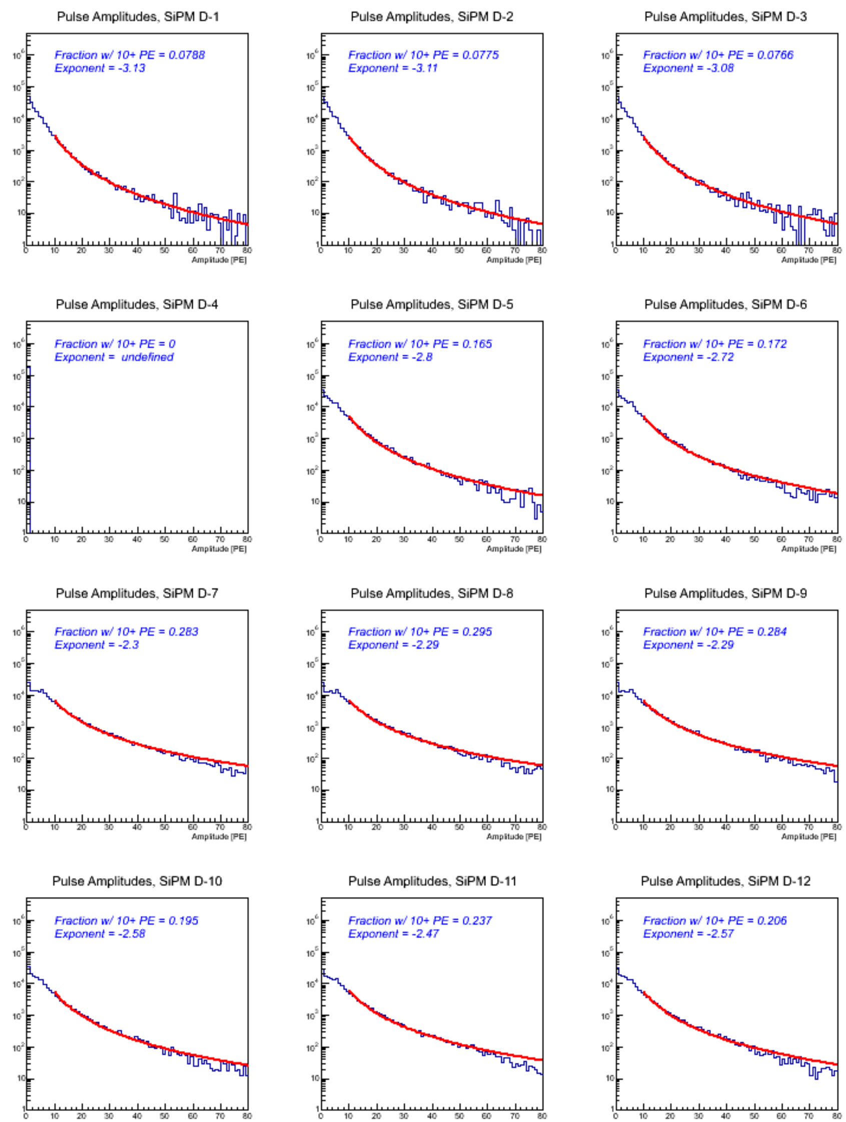
- “Free run” mode to collect light from all cosmics through dewar
  - Eventually collect light from all points in LAr volume
  - Even and comparable exposure of all bars



- “Free run” mode (self-triggered, OR of all SiPMs in a paddle)
  - Light from all cosmics through dewar
  - Look at distribution of calibrated signal amplitudes on each SiPM

- Each bar experiences approximately the same light exposure
  - Studied with toy MC

- Look for relative differences in light yield distributions
  - Total number of photons collected per hour
  - Shape of power-law fit to distribution
    - Longer tail indicates better efficiency



Bis-MSB 10

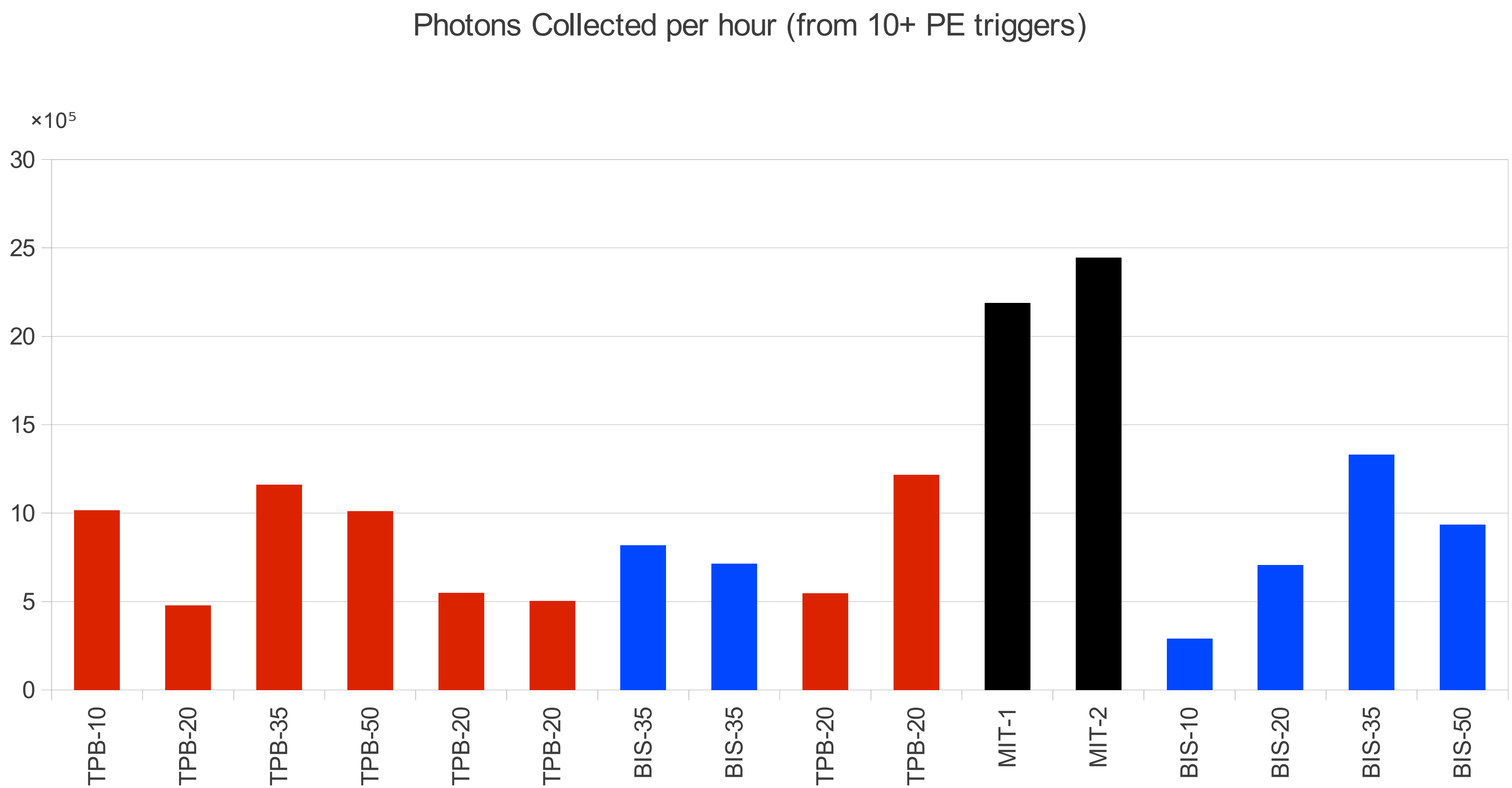
Bis-MSB 20

Bis-MSB 35

Bis-MSB 50

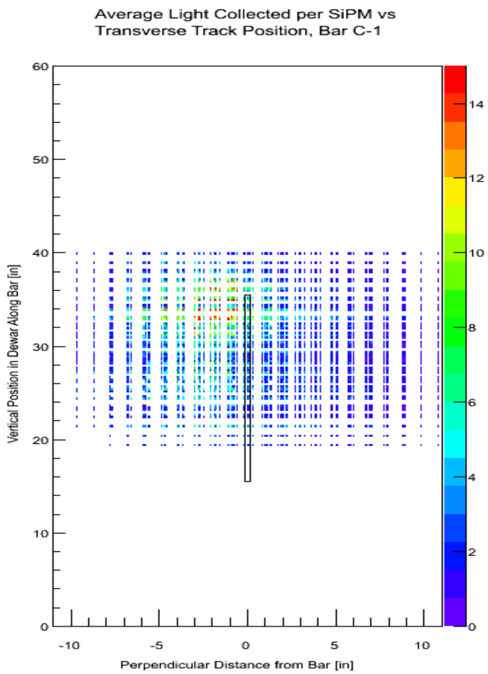
Light Yield Results (Free Run)

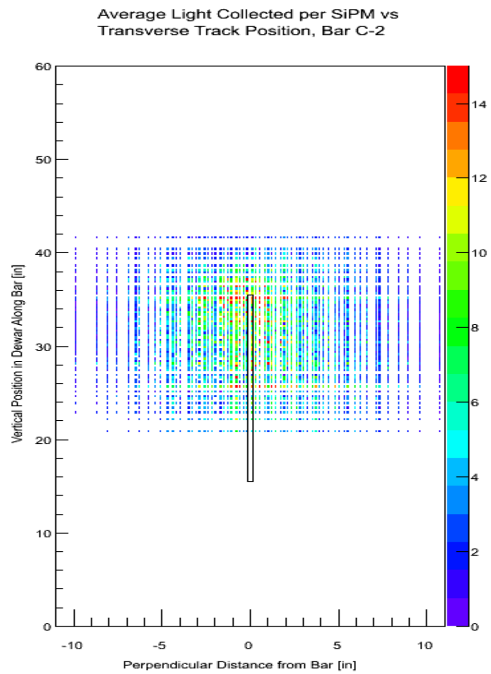
- Total number of photons collected per hour by each bar
  - Averaged over functional SiPMs

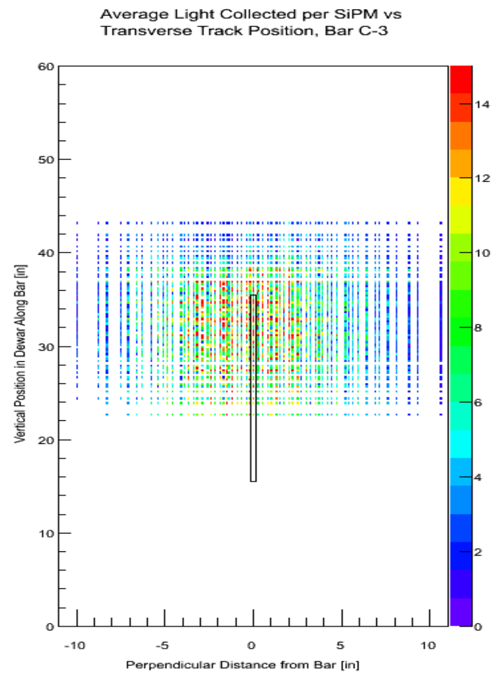


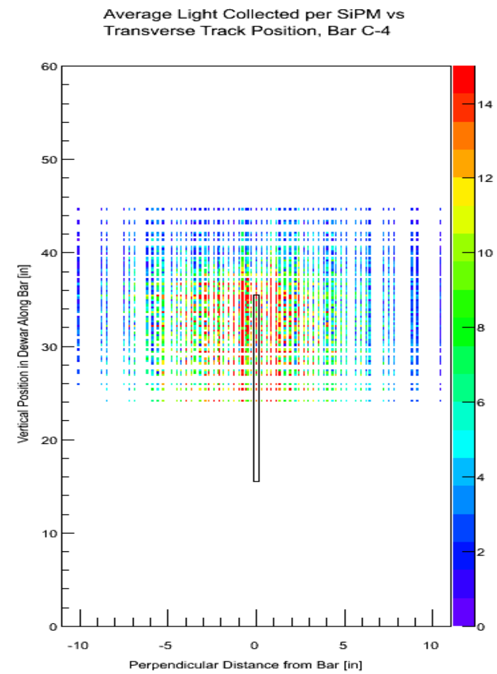
- 35 coats best option for both TPB & bis-MSB
- Hand-painted bars most efficient (but not a scalable method)

- Paddle C









- Average signal versus perp distance to bar

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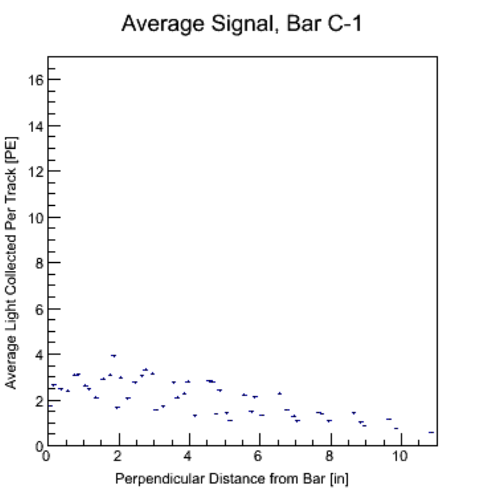
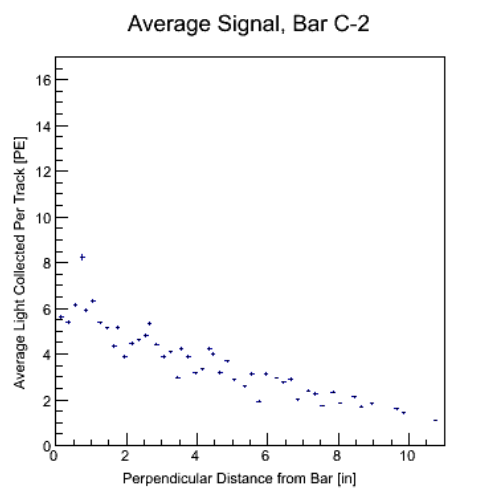
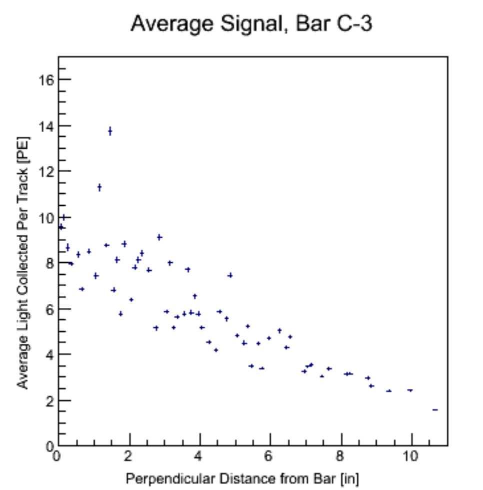
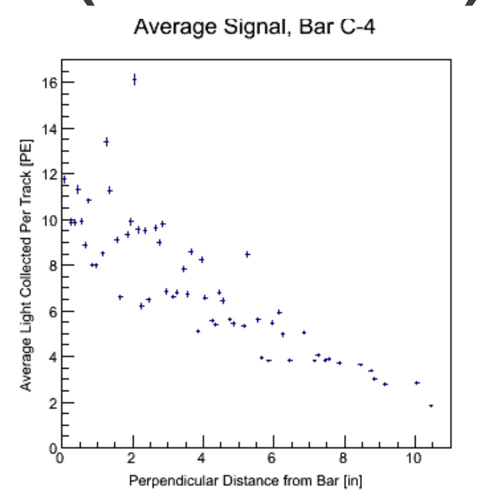








Conclusions from TallBo Run

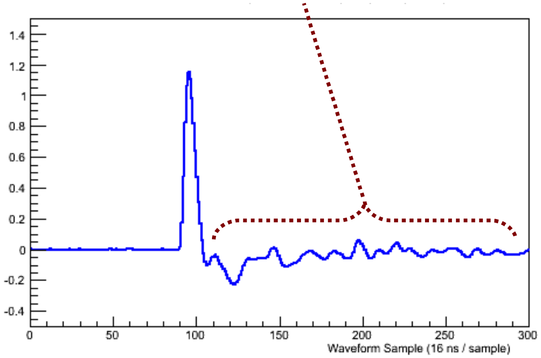
LBNE

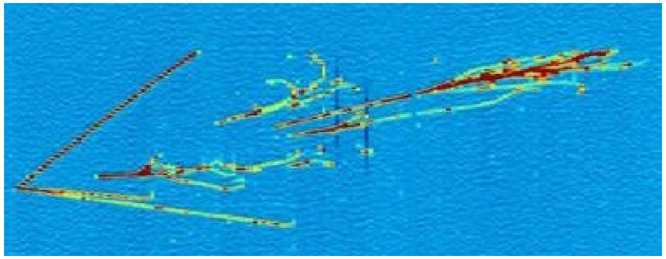
- Free run mode provides good handle on bar-to-bar performance comparisons
  - Two useful figures of merit
    - Total photons collected per hour
    - Shape of signal amplitude (PE) distribution
  - Consistent with intra-bar comparisons from hodoscope tracks
- Best flash-heated bars
  - TPB 20-35 coats
  - Bis-MSB 35 coats
- Hand-painted TPB bars overall best
  - Flash-heating may be damaging too much waveshifter
    - May also worsen surface quality (more losses at internal reflections)
  - "Artisan" bars not scalable manufacturing method
  - Assembling roll-coater to produce consistent bars
  - Testing cast acrylic doped with 1% TPB
- Mechanical malfunction led to loss of signal from 7 SiPMs
  - Have revised SiPM mount design

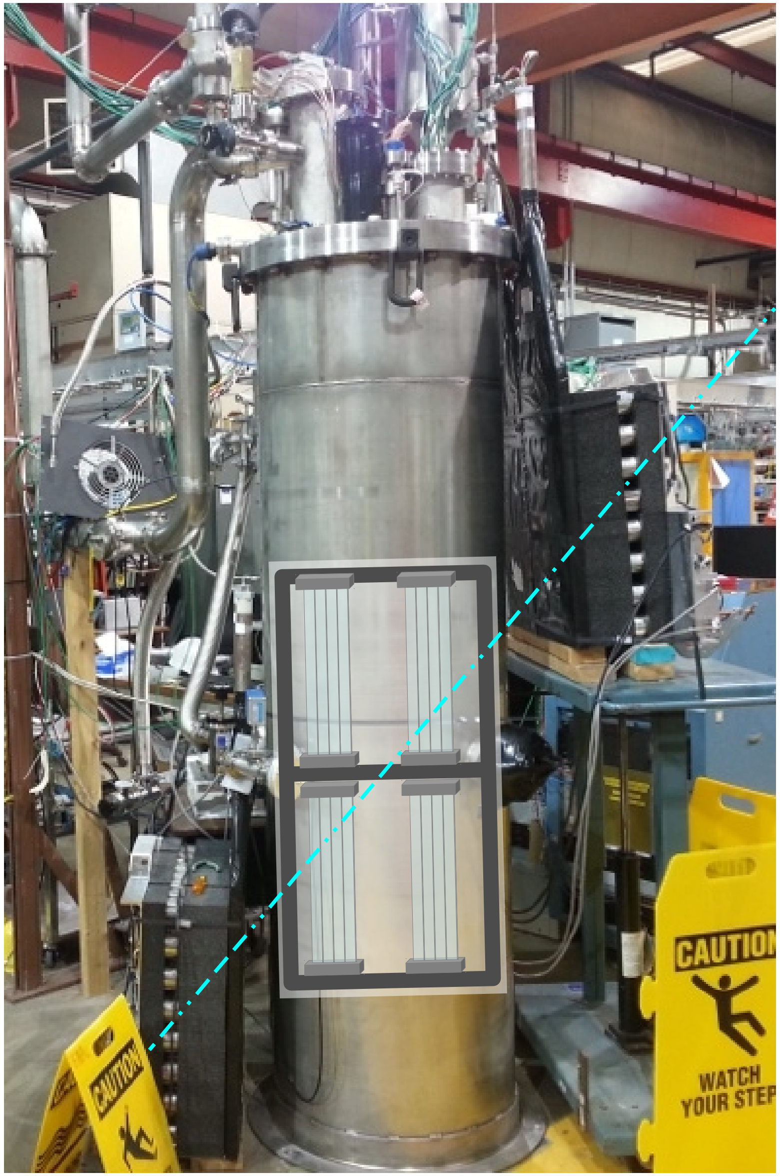
Conclusions from TallBo Run

- LBNE Photon Detector prototype tests continue
  - TallBo experience was very valuable
    - much experience & insight gained
    - several revisions underway

- Analyses continuing
  - Bar-to-bar comparisons
  - Light yield vs track position
  - Effects of Xe-doped LAr
  - Properties of late light signal







- Ready for round two!
  - Investigating alternatives to flash heating
  - Looking forward to testing new ideas

- Big thanks to everyone who helped make this possible!

- Indana U.
  - Stuart Mufson, Jim Musser, Mark Gebhard, Brice Adams, Mike Lang, Brian Baugh, Paul Smith, Tad Baptista, Bryan Martin
- MIT
  - Janet Conrad, Matt Toupes, Zander Moss, Ben Jones, Len Bugel
- Colorado State U.
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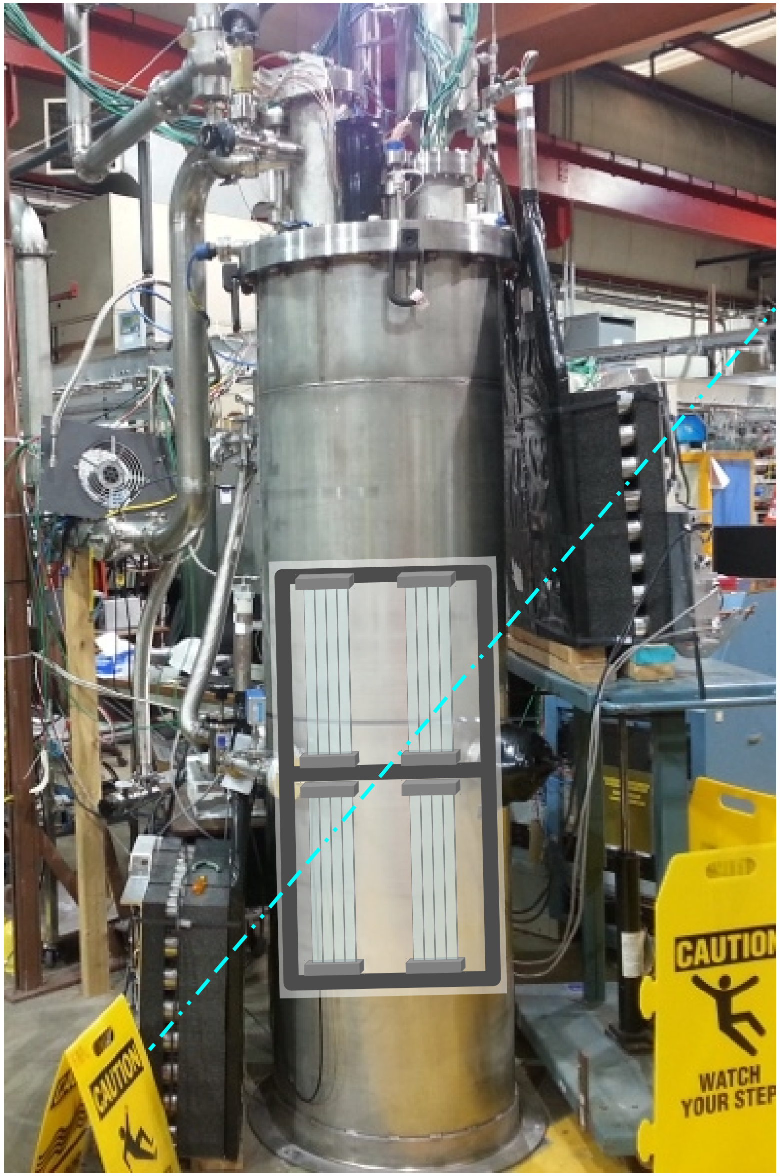
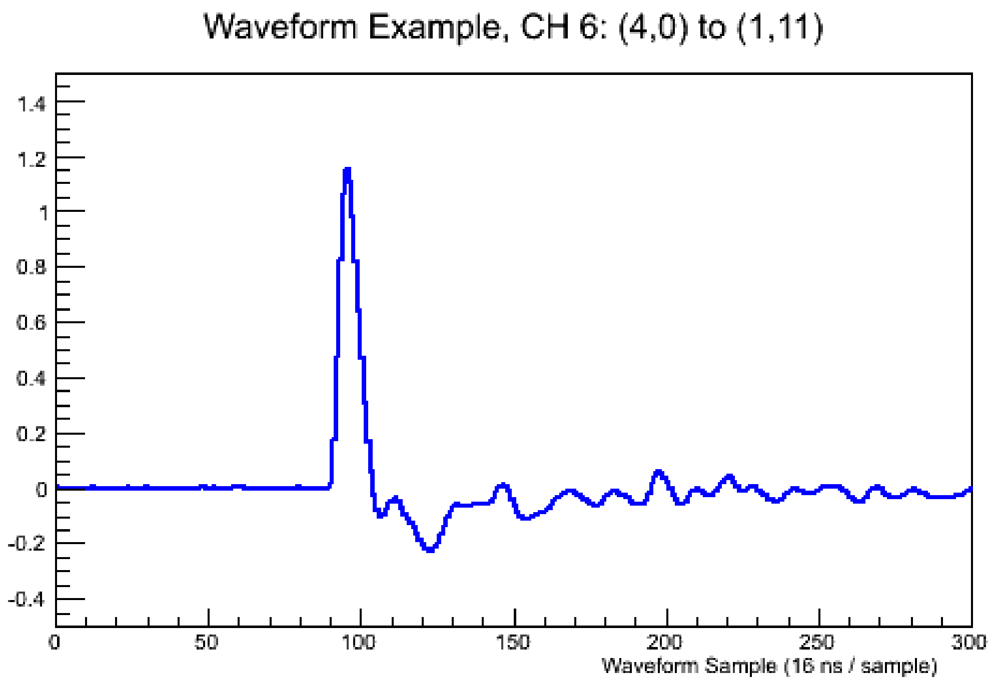
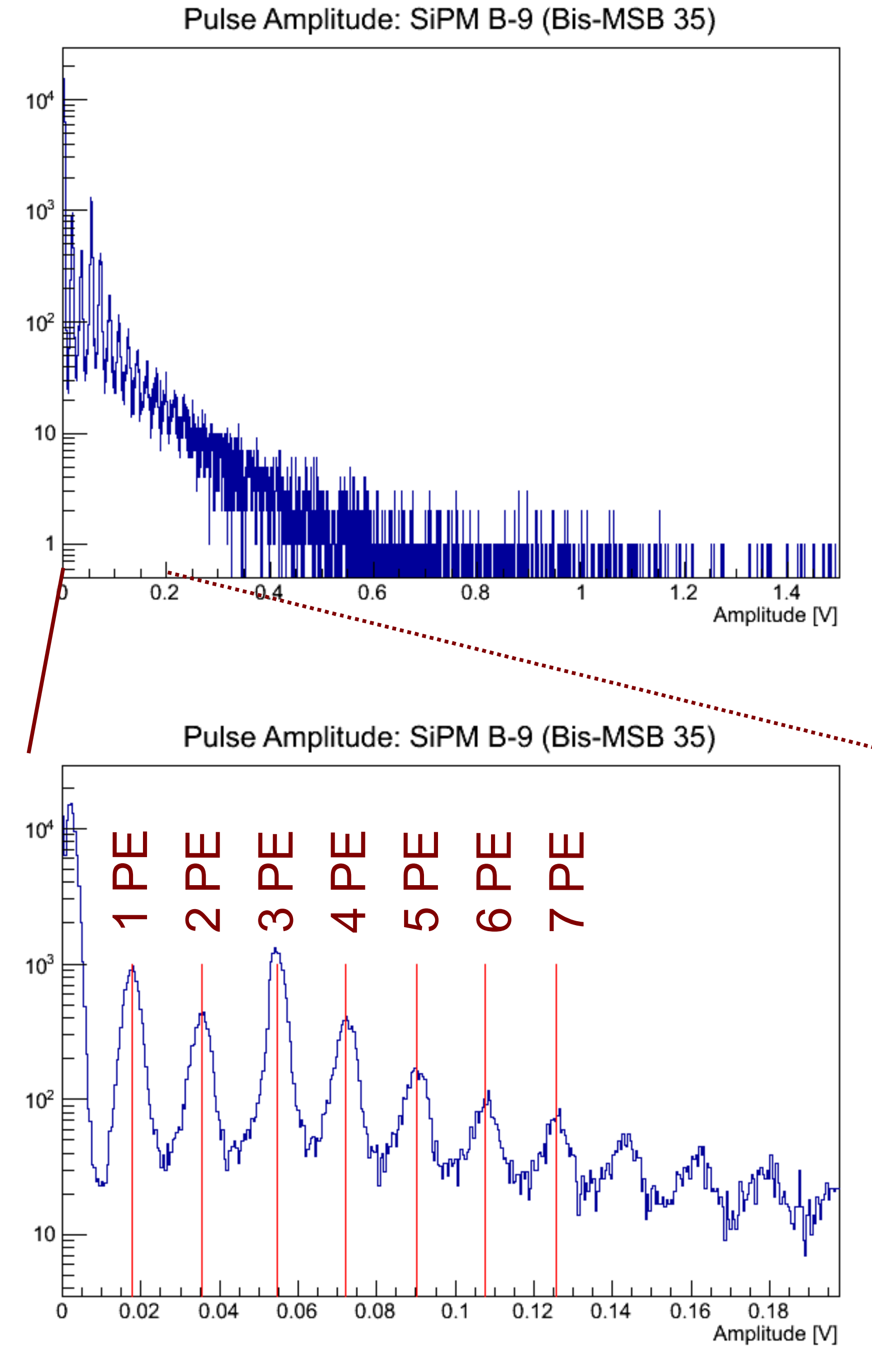
- Argonne Natl. Lab
  - Gary Drake, Patrick De Lurgio, Zelimir Djurcic, Himansu Sahoo, Vic Guarino
- Fermilab
  - Brian Rebel, Stephen Pordes, Ron Daves, Bill Mills, Marvin Johnson



Backup





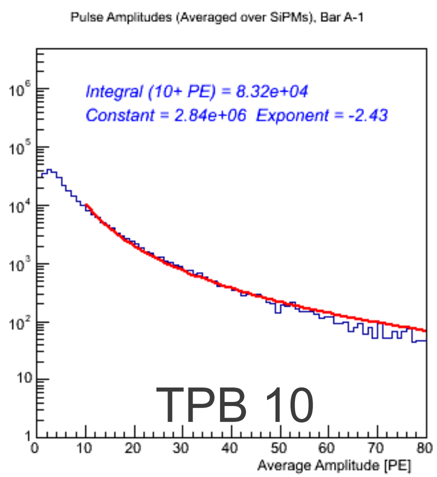
- Leading pulse from prompt scintillation (τ ~ 6 ns)
- Post-pulse activity from secondary scintillation (τ ~ 1.6 μs)

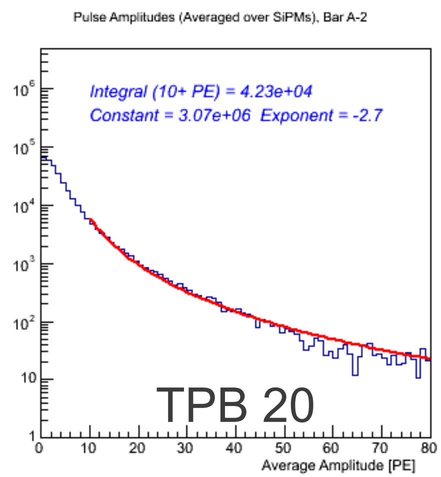
- Pulse heights fall into discrete values, corresponding to integer photoelectron signals

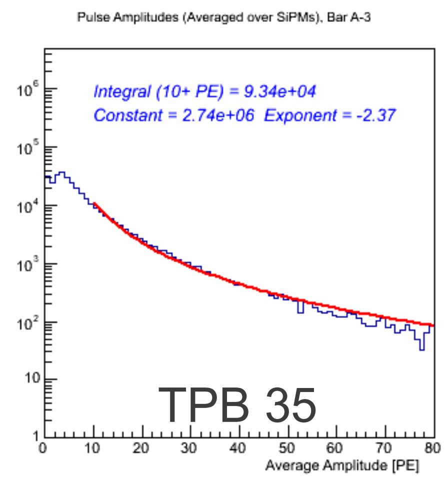
Light Yield Comparisons (Free Run)

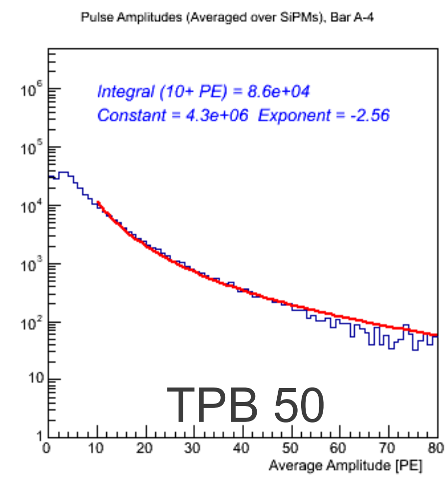
LBNE

- ## Paddle A

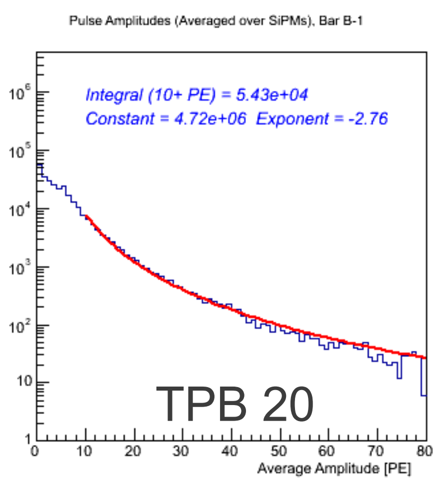


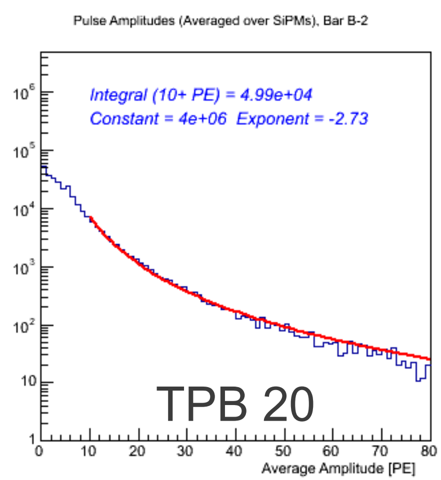


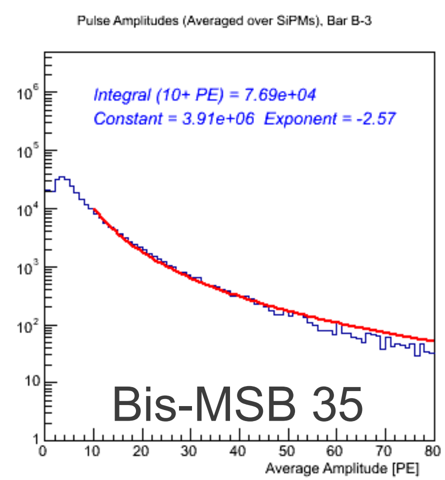


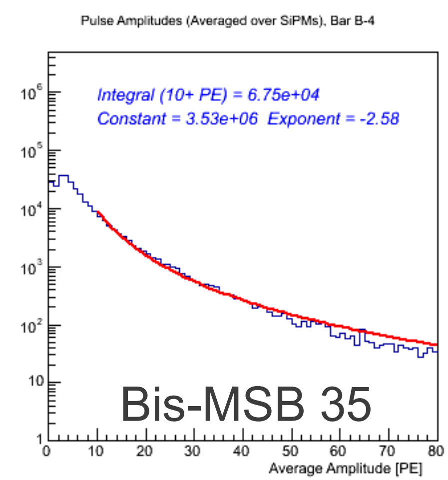


- ## Paddle B









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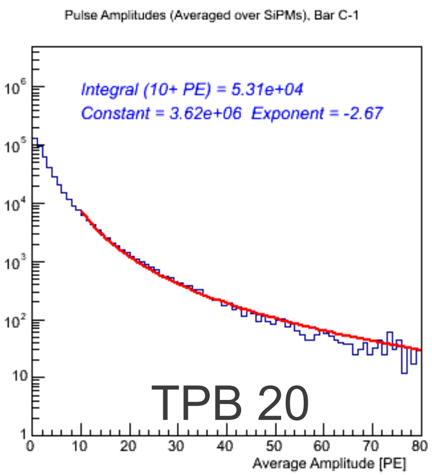
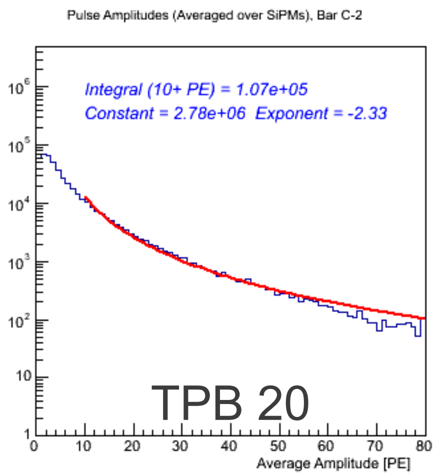
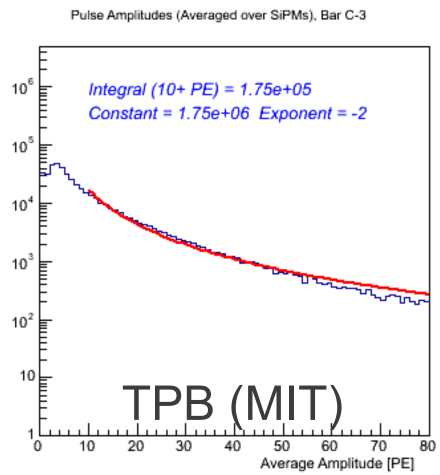
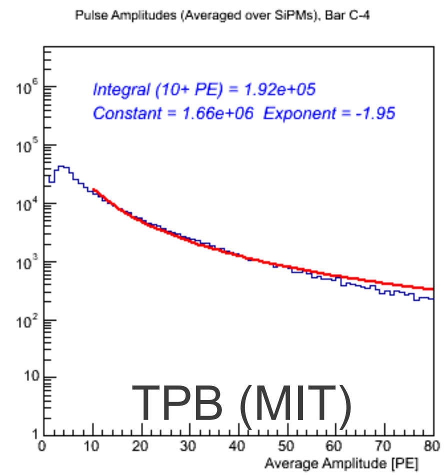
- Paddle C

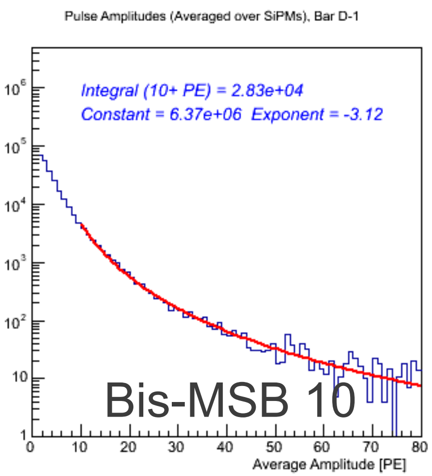


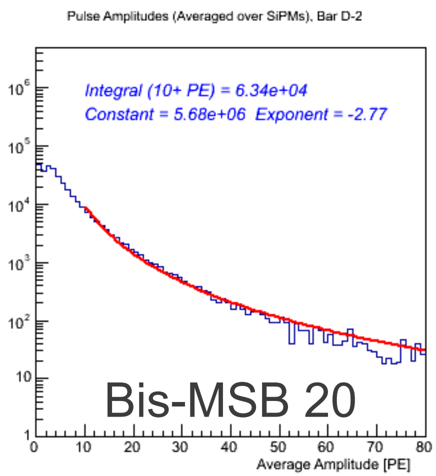


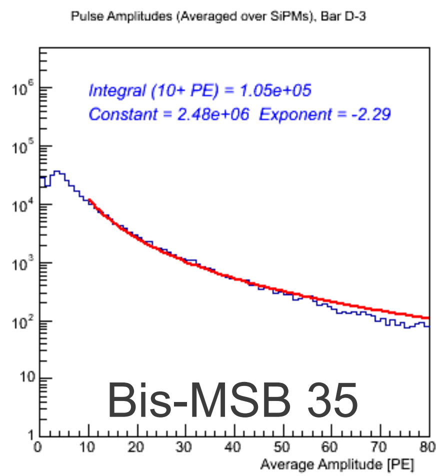


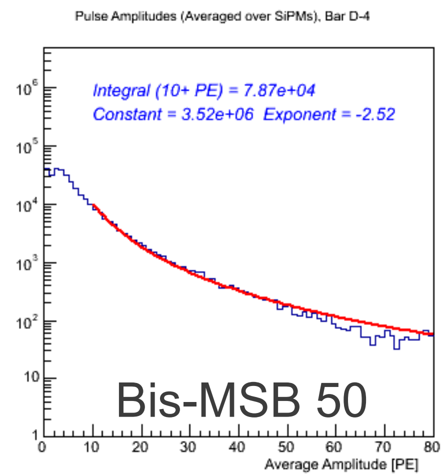


- Paddle D

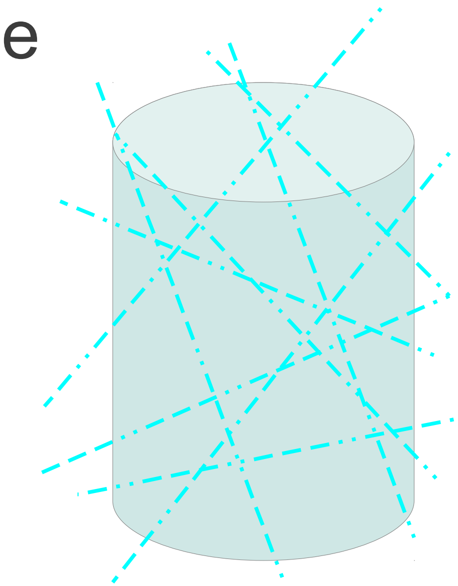


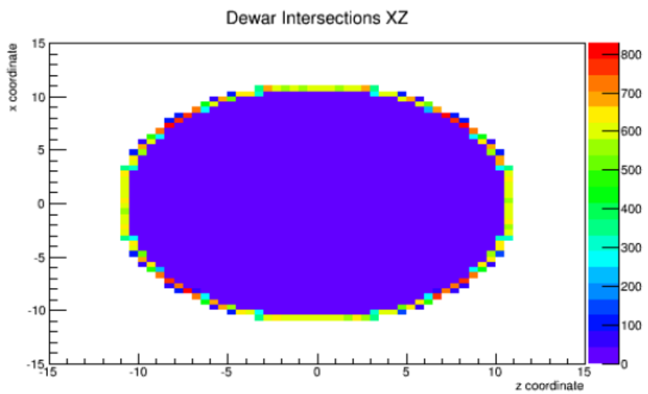


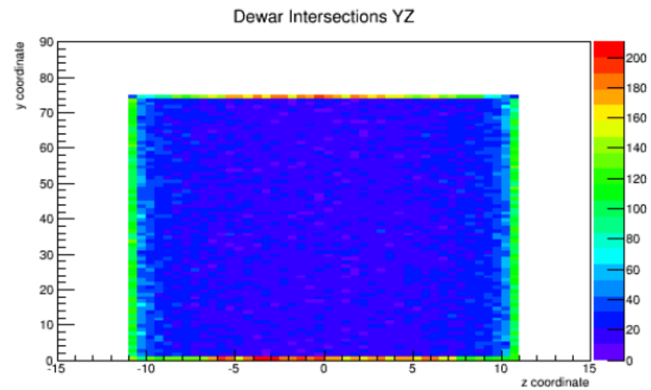




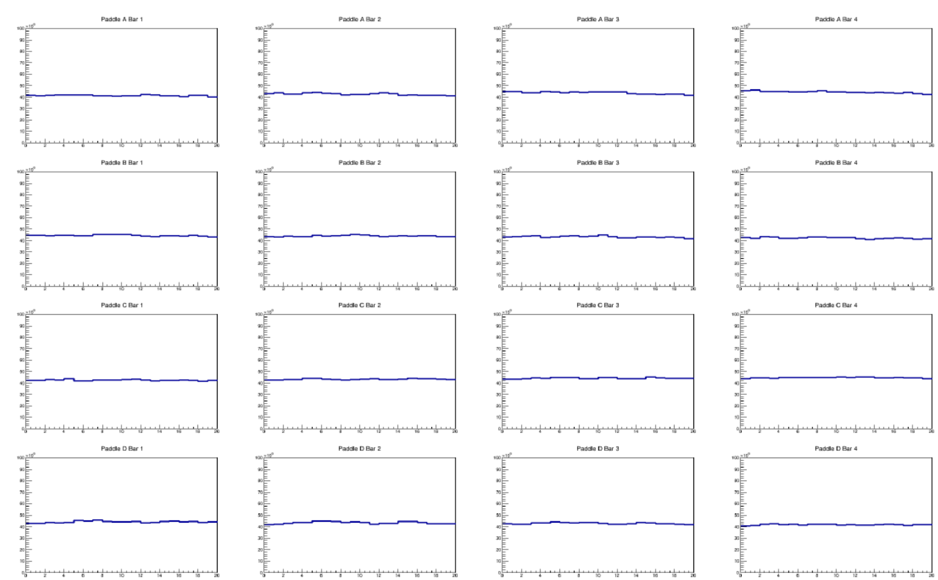
- Simulate light from cosmics through LAr volume
  - Johnathon Lowery (IU)
  - Throw cosmic ray, throw photons along track, see how much hits each bar along length





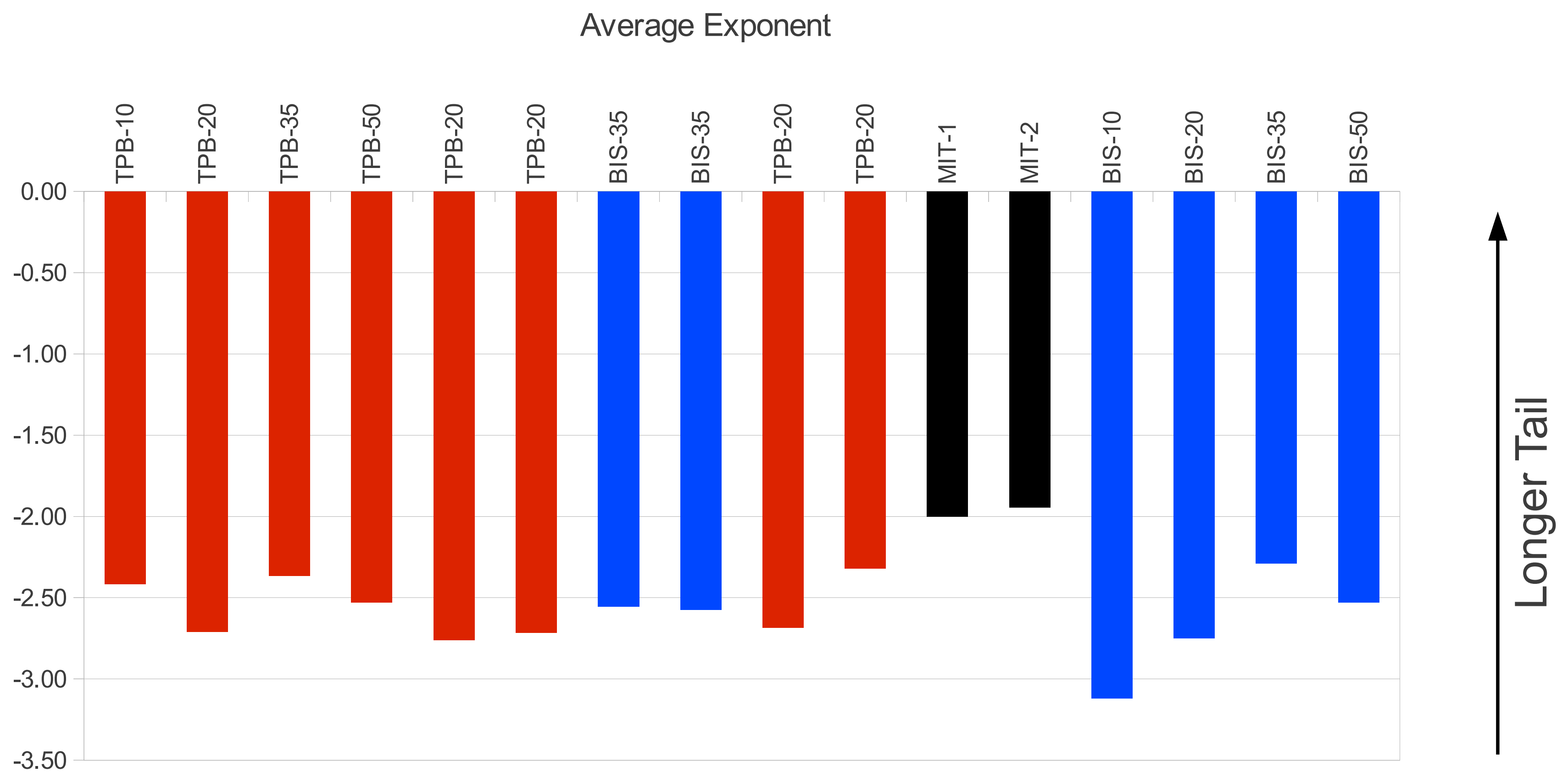


- Scintillation exposure versus position along bar
  - All bars receive approximately the same number of photons along length
  - Minimal variation between bars in different paddles
  - Confident this is a good metric

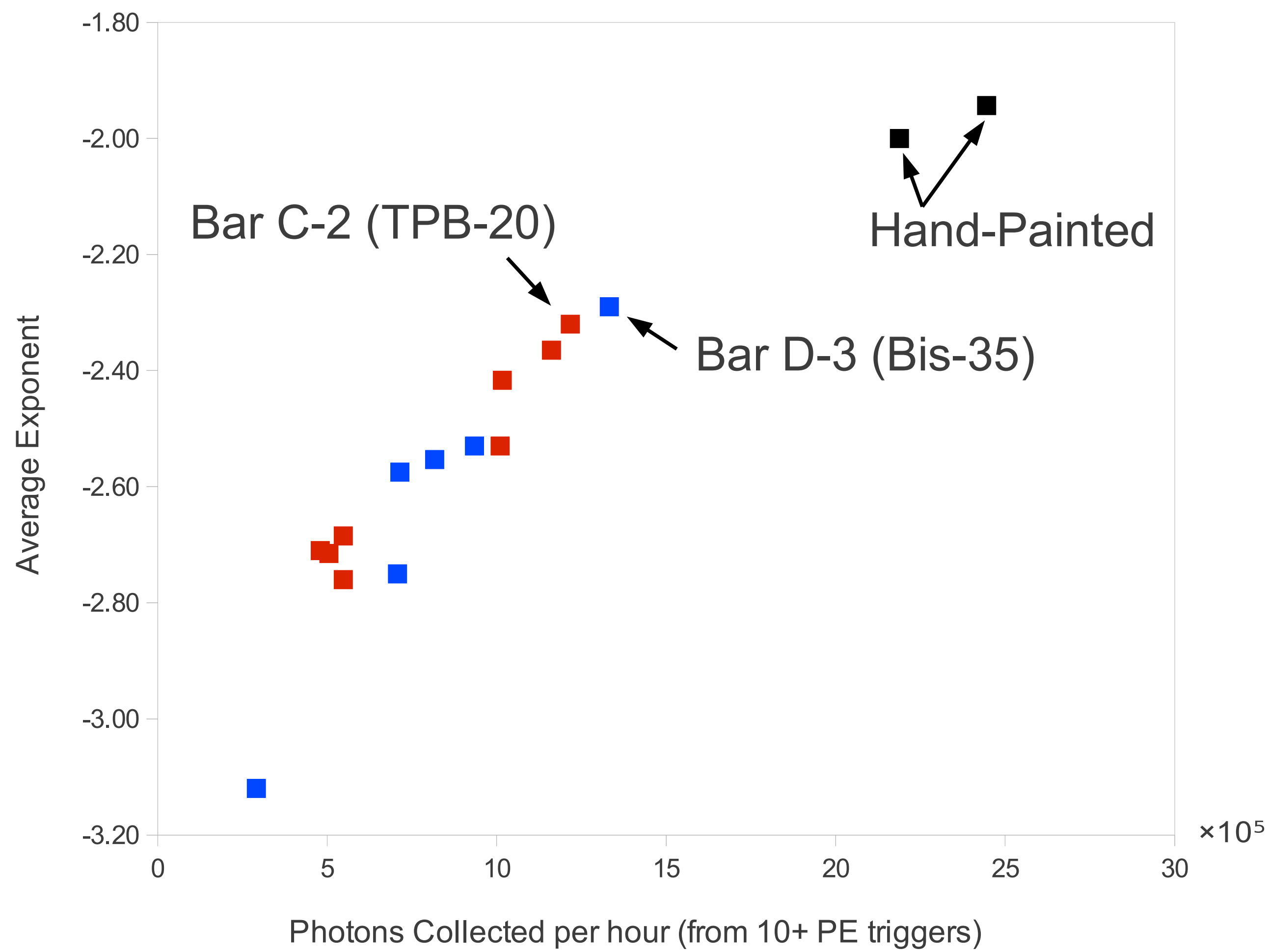


LBNE

- Exponent
  - (smaller is better!)



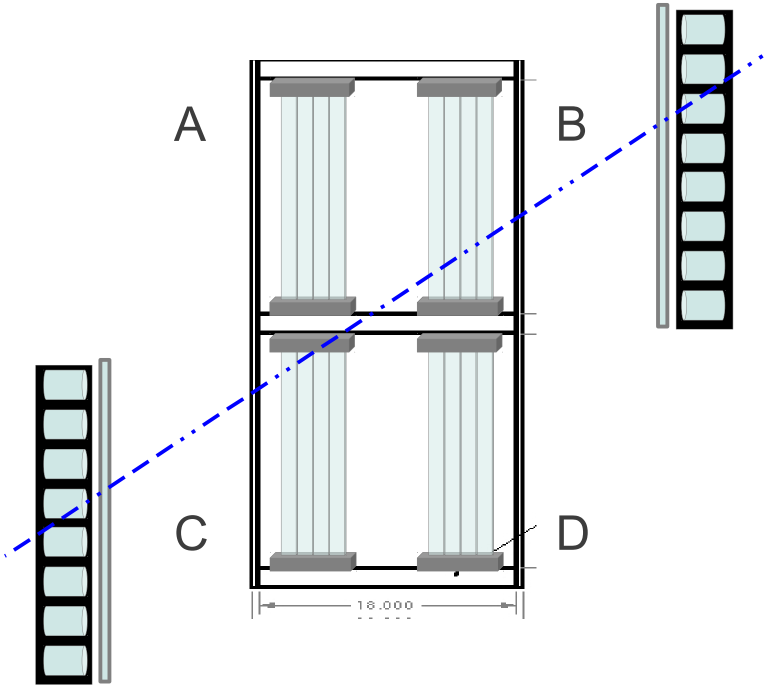
- Both figures of merit well correlated



CREST Hodoscope Trigger

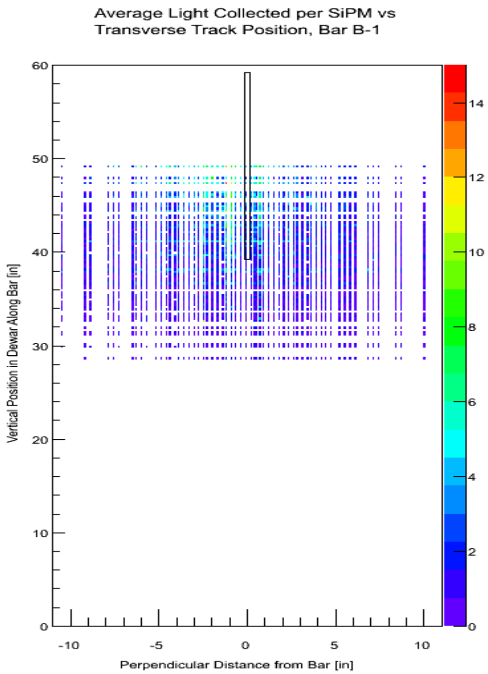
- Two 8x8 Arrays of PMTs from CREST balloon-based cosmic ray experiment
  - Barium-fluoride crystals with TPB coating
  - Positioned on opposite sides of dewar (one elevated 48”)
- Plastic scintillator paddles
  - Gamma (Compton, etc.) veto
    - BaF_2 crystals sensitive to x-rays

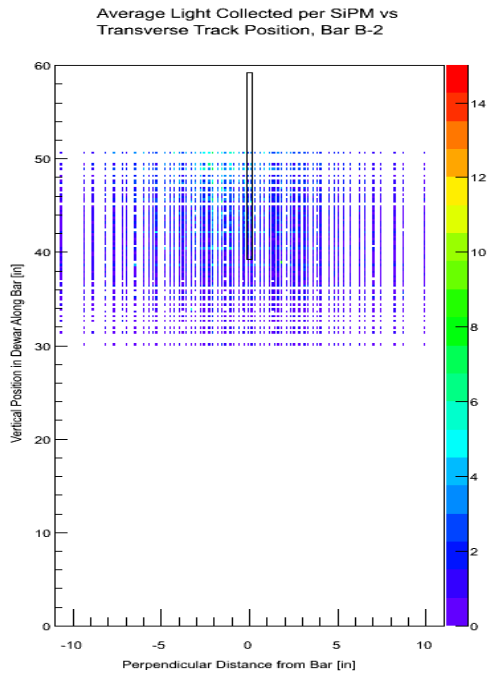
- Shower vs single particle discrimination
- Approximate track reconstruction

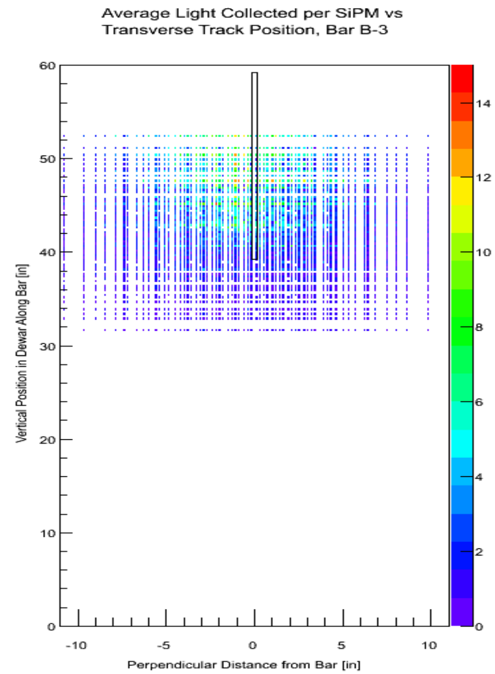


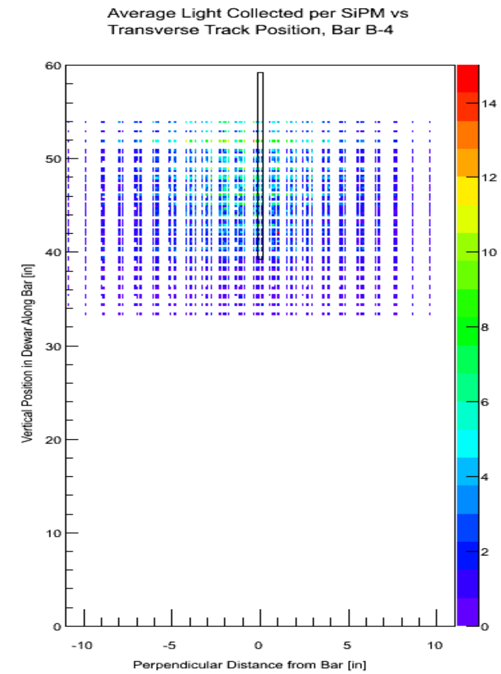
- Four-fold coincidence trigger
  - >1 PMT on each array
  - One paddle on each side
  - ~2 Hz 4-fold trigger rate

- Paddle B (Tracks far from readout = weaker average signal)









- Average signal versus perp. distance to bar

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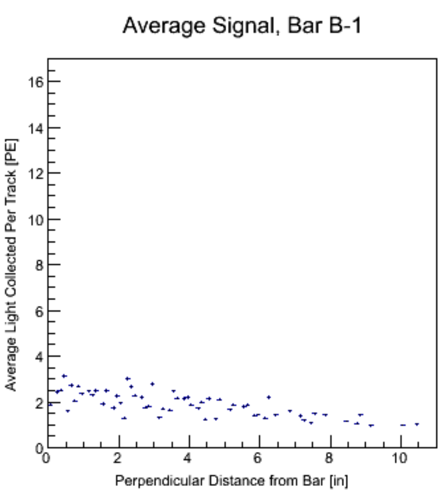
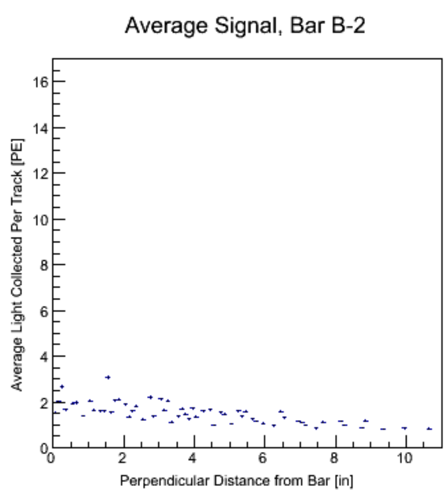
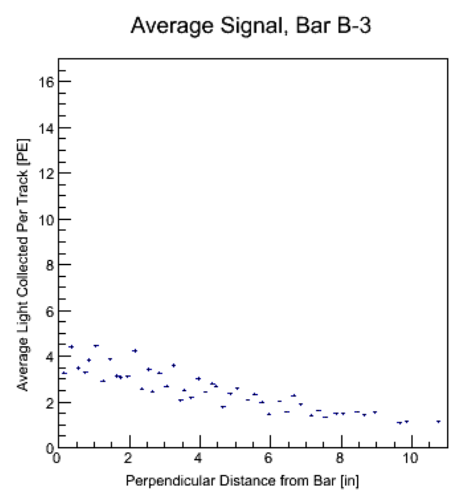
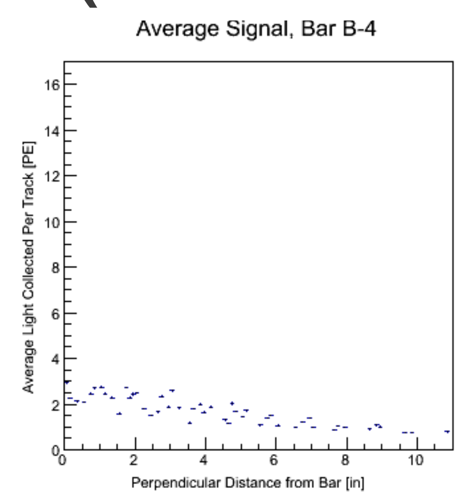




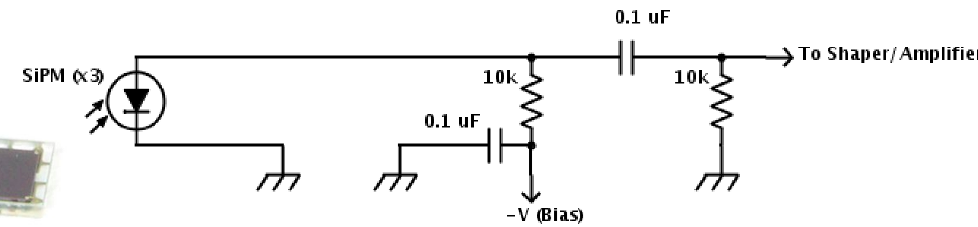




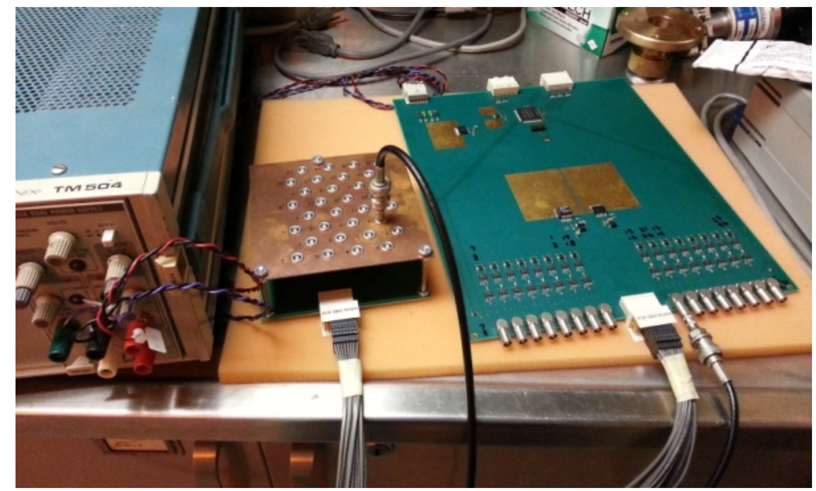
Plans for TallBo 2

- Returning to PAB starting February 24th
- New technologies
  - New custom readout electronics from G. Drake et. al. (ANL)
  - New cables (twisted pair)
    - previous found to be prone to noise pickup
  - Test of new LED-based calibration system (Z. Djurcic)
- Larger diversity of bar designs
  - Flash-heated TPB (35 coats) and Bis-MSB (35 coats) (IU)
  - Cast with TPB (IU)
  - Cast with TPB (LBNL)
  - Dip-coated TPB (MIT)
  - Fiber mounts (CSU)
  - Roll-coat painted (IU)
- Will rely on free-run mode for primary bar-to-bar performance comparisons, with hodoscope as cross-check.

- Set of 3 independent SiPMs
  - SensL MicroFB-60035-SMT
  - 24.5 V bias

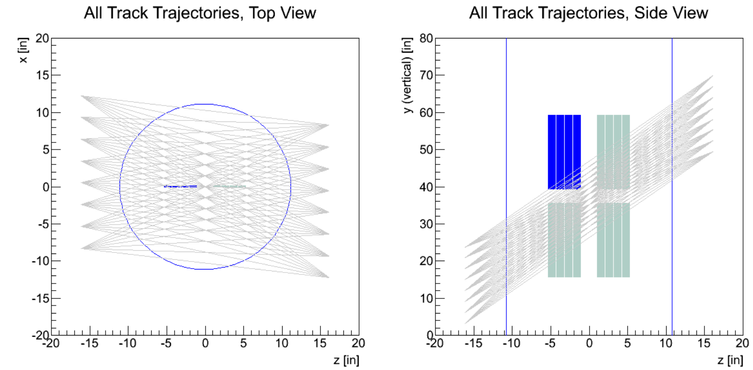


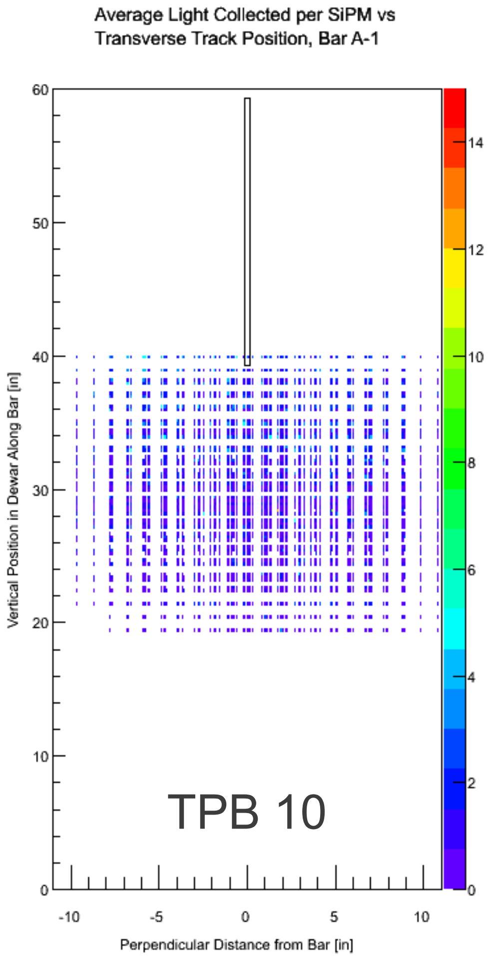
- Nevis shaper/amplifier
  - Differential shaping
  - Gain ~ 200x

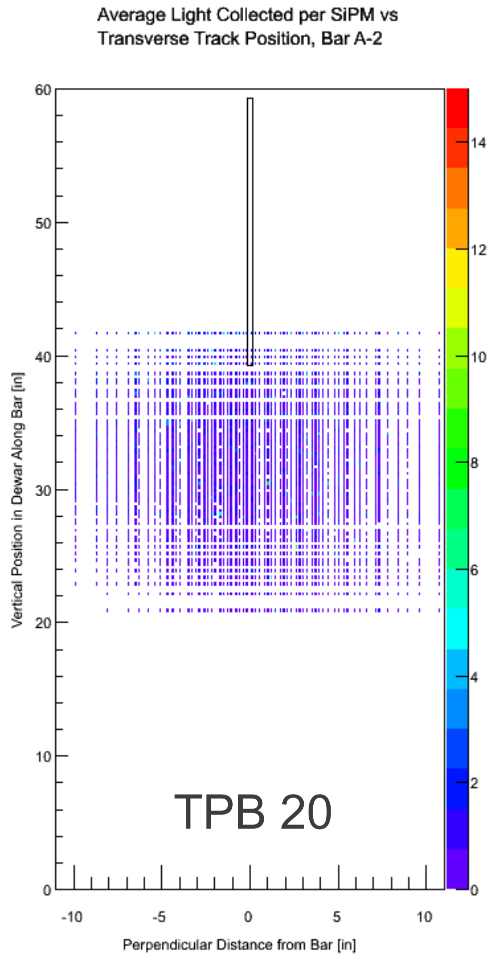


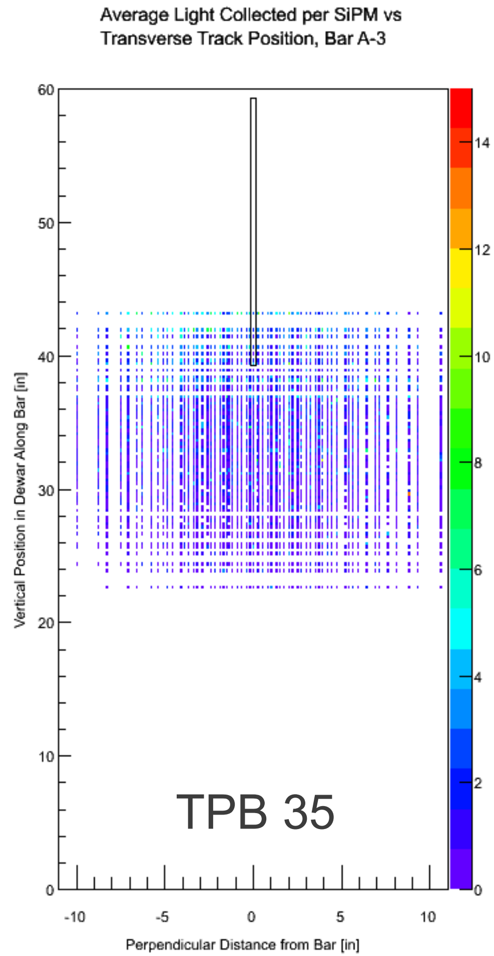
- CAEN DT5740
  - 32 input channels
  - 62.5 MHz sample rate
    - (16 ns / sample)
  - 0.48 mV / ADC Count
    - (12-bit, 2 V pp input range)

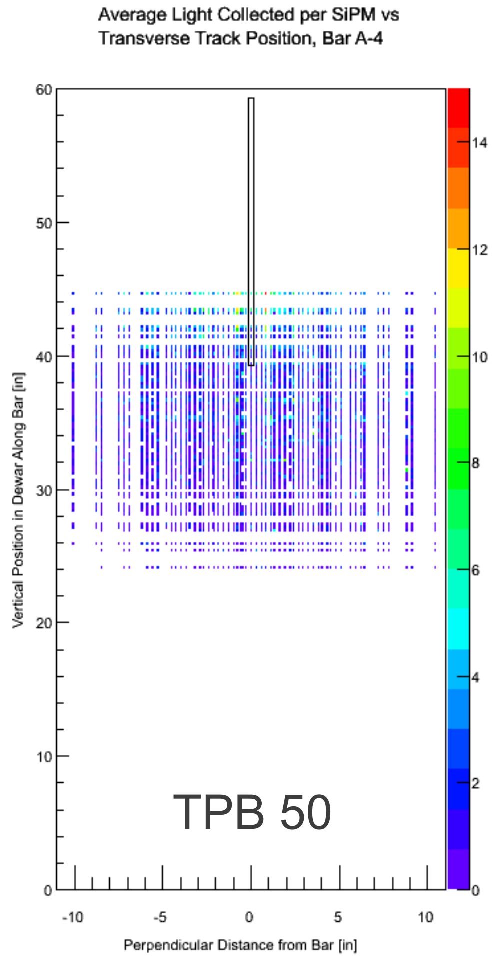
- Yields vs Track Proximity, Paddle A





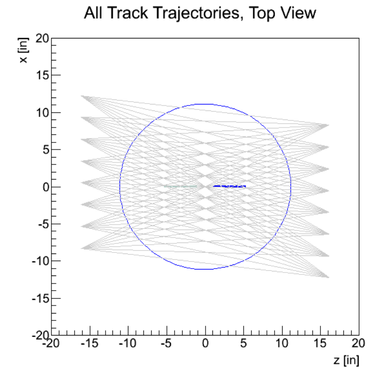


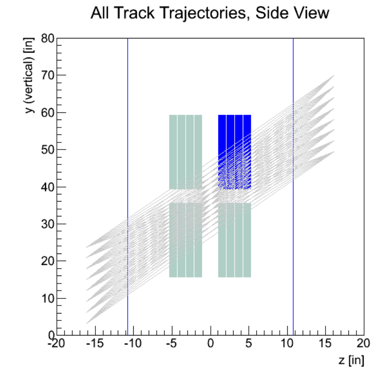


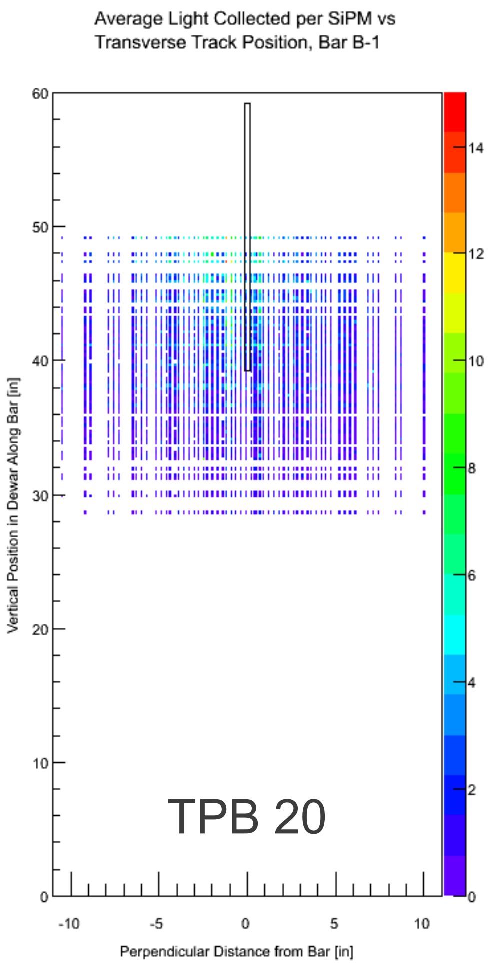


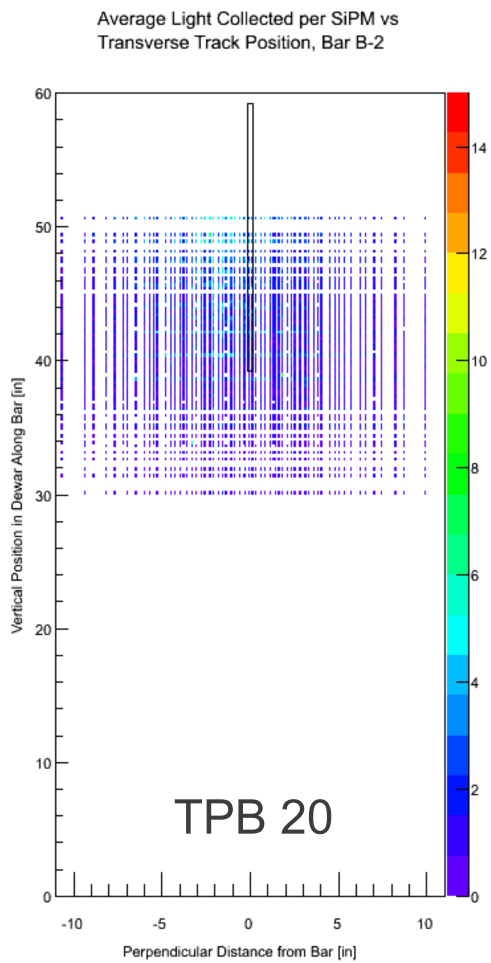
Hodoscope – Tracks

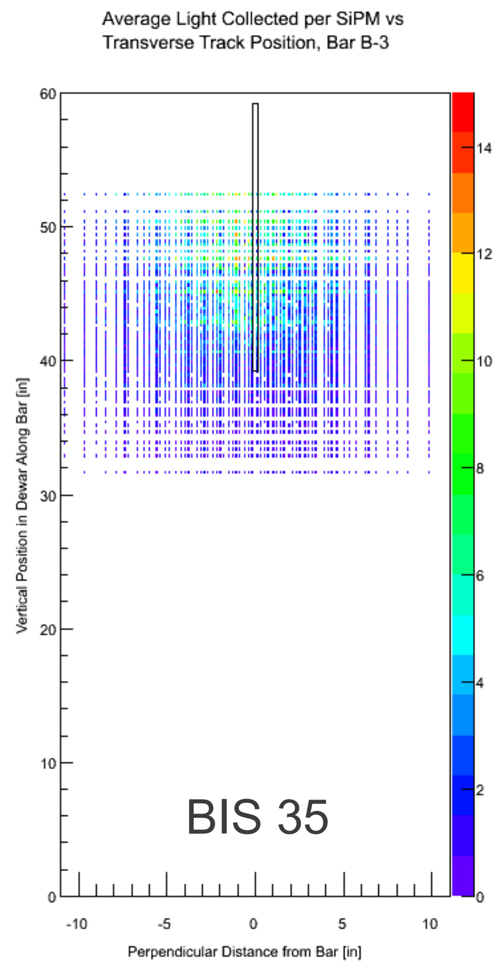
- Yields vs Track Proximity, Paddle B

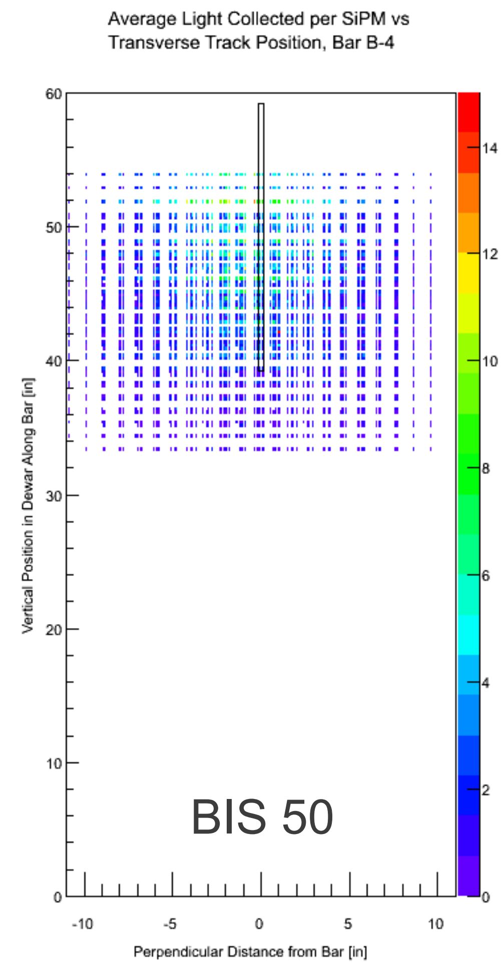




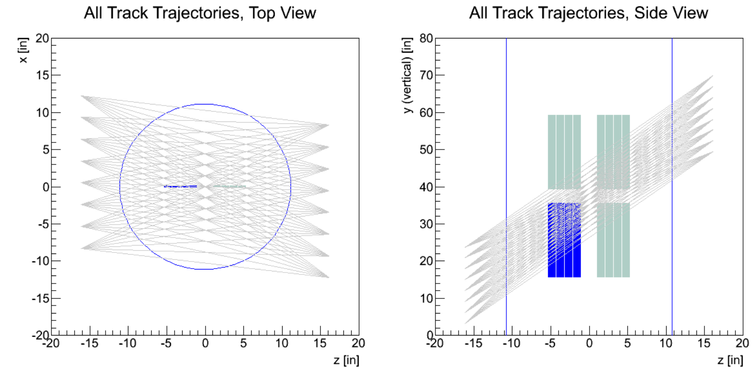


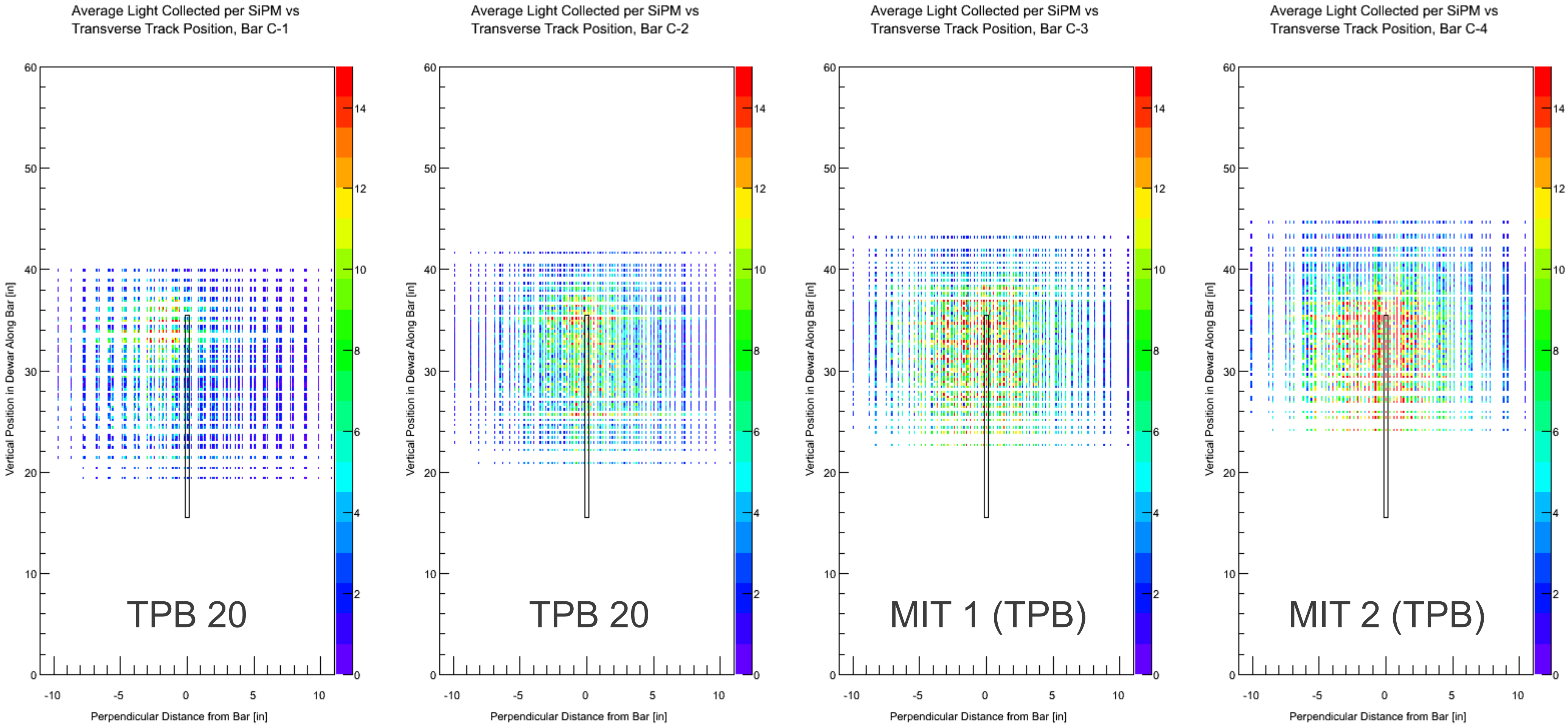




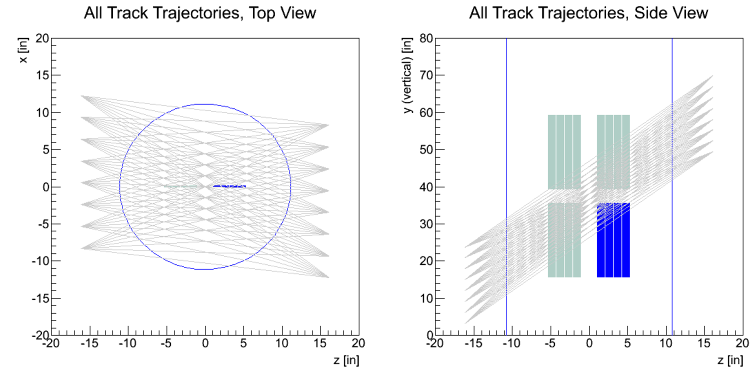


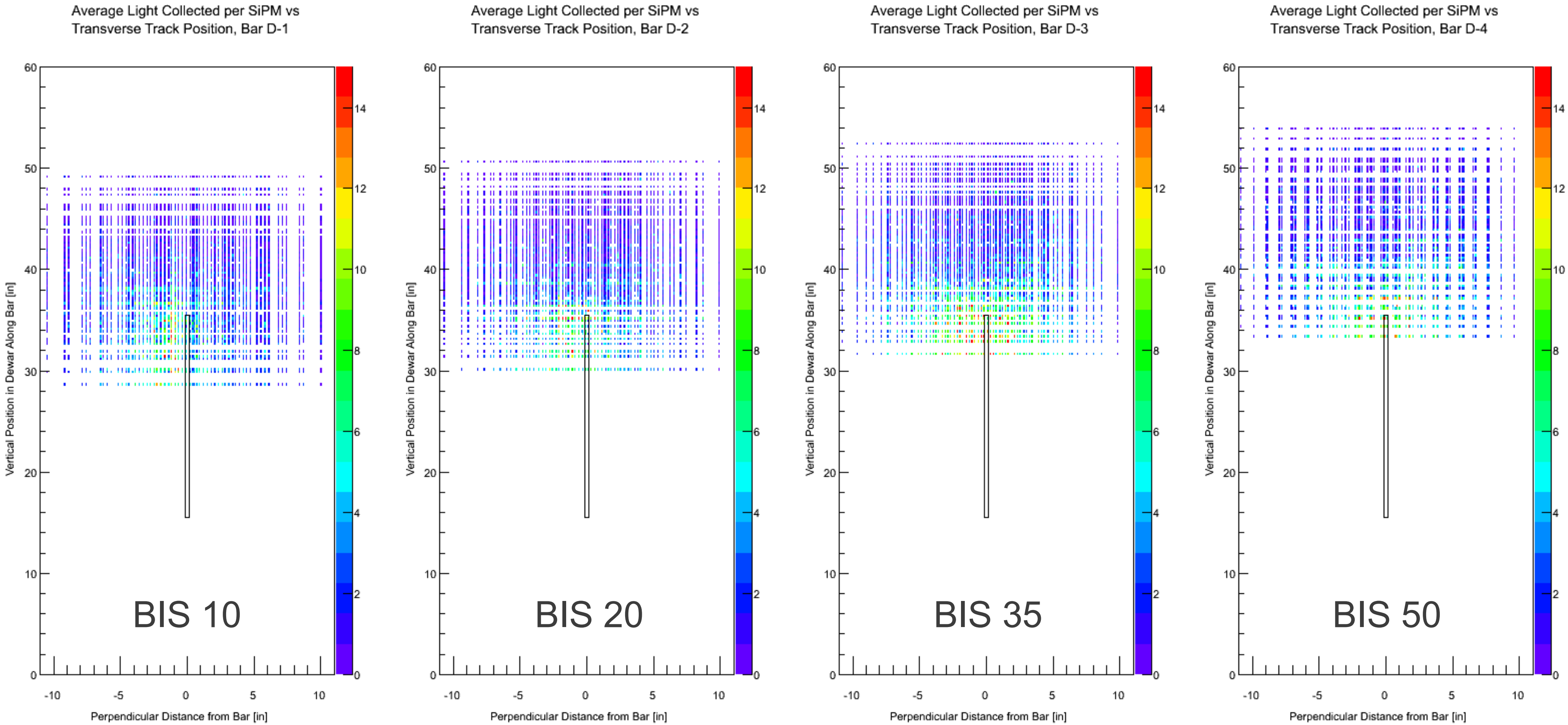
- Yields vs Track Proximity, Paddle C





- Yields vs Track Proximity, Paddle D

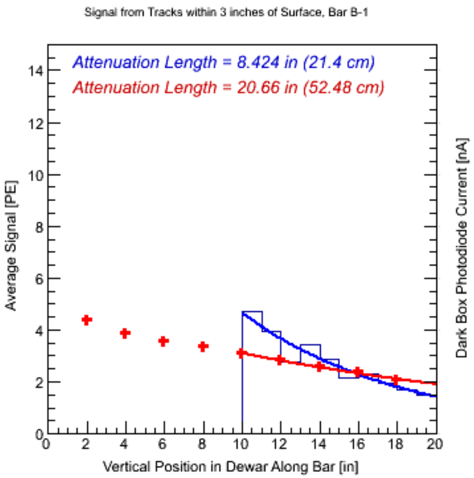


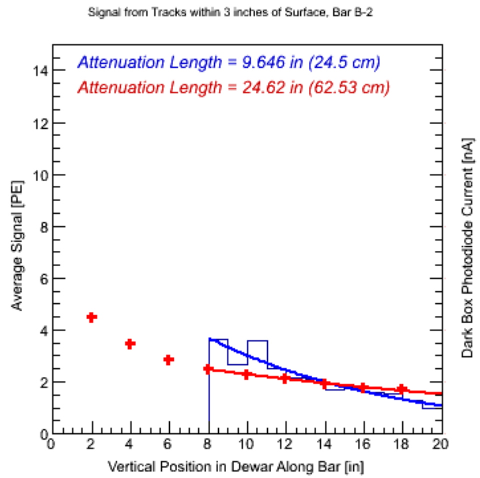


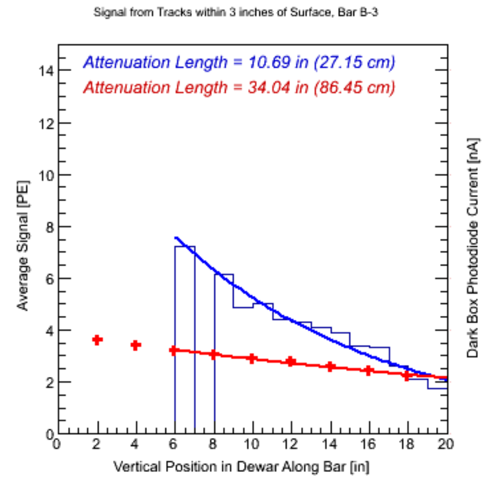
Comparison to Dark Box (245 nm LED)

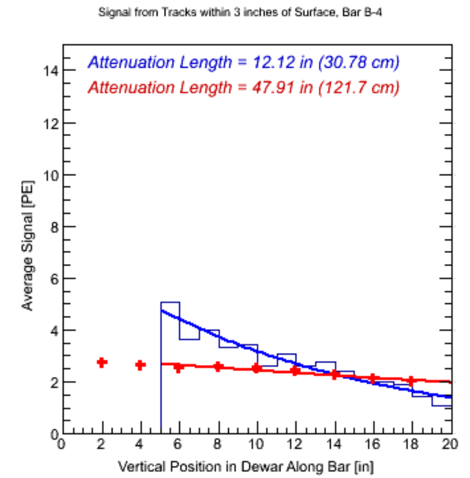
LBNE

- Attenuation Length Measurement in LAr
  - Select tracks within 3 inches of bar surface
- Paddle B

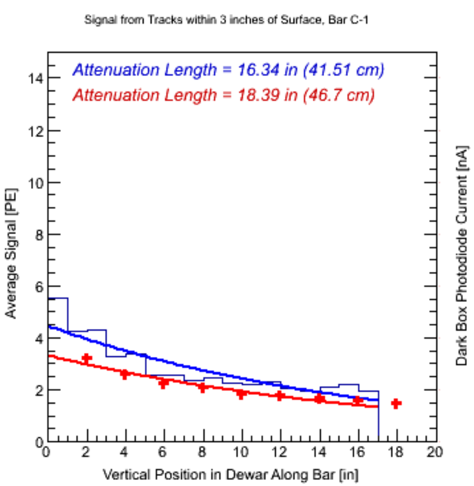


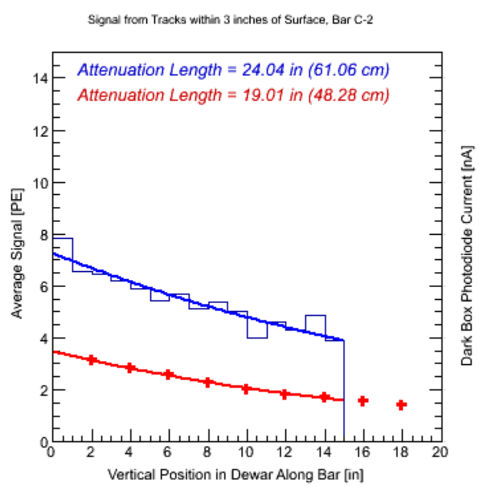


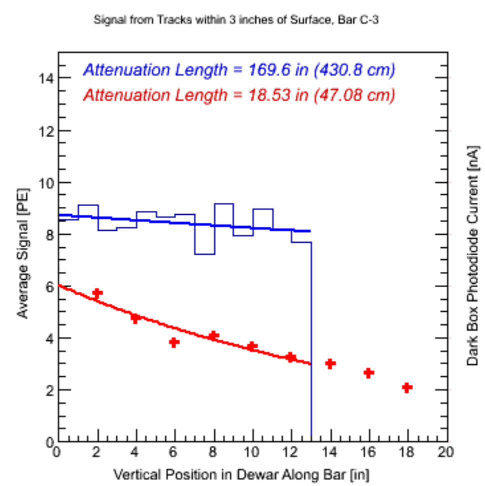


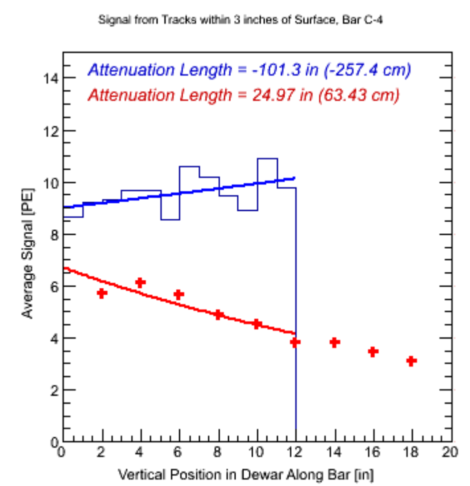


- Paddle C









- Possible increase of losses at surface (internal reflection)
- Simulated light bouncing down length of acrylic bar in LAr

- Very minor effect going from air to liquid argon

- Can mimic change in attenuation length by increasing surface loss %